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Wayne E. Sabbe Arkansas Soil Fertility Studies 2012

Nathan A. Slaton
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Wayne E. Sabbe ARKANSAS SOIL FERTILITY STUDIES

• 2012 •

Nathan A. Slaton, Editor

DIVISION OF AGRICULTURE
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Cover: Peanuts were grown on an estimated 18,000 acres in Arkansas during 2012. The photograph shows a nitrogen deficient strip of peanuts (right side) in a Mississippi County production field near Manila, Ark. compared to peanuts with sufficient N (left side). The nitrogen deficiency was caused by an equipment problem that resulted in no Bradyrhizobium inoculum being applied to the peanut seed at planting. Like soybean, peanuts are a legume and are capable of fixing or using N_2 gas present in the atmosphere when the proper N-fixing bacteria are present in the soil. (photograph by Dave Freeze, County Extension Agent–Staff Chair Mississippi County).

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WAYNE E. SABBE ARKANSAS SOIL FERTILITY STUDIES
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SUMMARY

Rapid technological changes in crop management and production require that the research efforts be presented in an expeditious manner. The contributions of soil fertility and fertilizers are major production factors in all Arkansas crops. The studies described within will allow producers to compare their practices with the university's research efforts. Additionally, soil-test data and fertilizer sales are presented to allow comparisons among years, crops, and other areas within Arkansas.

INTRODUCTION

The 2012 Soil Fertility Studies include research reports on numerous Arkansas commodities and several disciplines. For more information on any topic, please contact the author(s). Also included is a summary of soil-test data from samples submitted during 2011. This set of data includes information for counties, soil associations, physiographic areas, and selected cropping systems.

Funding for the associated soil fertility research programs came from commodity check-off funds, state and federal sources, various fertilizer industry institutes, and lime vendors. The fertilizer tonnage fee provided funds not only for soil testing but also for research and publication of this research series.

Mention of a trade name is for facilitating communication only. It does not imply any endorsement of a particular product by the authors or the University of Arkansas System Division of Agriculture, or exclusion of any other product that may perform similarly.

Extended thanks are given to the staff at state and county extension offices, as well as at research centers and stations; farmers and cooperators; and fertilizer industry personnel who assisted with the planning and execution of the programs.

This publication is available as a web-only research series book online at http://arkansasagnews.uark.edu/1356.htm.

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Soil-test and Fertilizer Sales Data: Summary for the 2011 Growing Season

R.E. DeLong, S.D. Carroll, N.A. Slaton, M. Mozaffari, and C. Herron

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soil-test data from samples submitted to the University of Arkansas System Division of Agriculture Soil Testing and Research Laboratory in Marianna between 1 January 2011 and 31 December 2011 were categorized according to geographic area (GA), county, soil association number (SAN), and selected cropping systems. The GA and SAN were derived from the General Soil Map, State of Arkansas (Base 4-R-38034, USDA, and University of Arkansas Agricultural Experiment Station, Fayetteville, Ark., December, 1982). Descriptive statistics of the soil-test data were calculated for categorical ranges for pH, phosphorus (P), potassium (K), and zinc (Zn). Soil pH and Mehlich-3 extractable (analyzed using inductively coupled plasma spectroscopy, ICAP) soil nutrient (i.e., P, K, and Zn) availability index values indicate the relative level of soil fertility.

RESULTS AND DISCUSSION

Crop Acreage and Soil Sampling Intensity

Between 1 January 2011 and 31 December 2011, 178,632 soil samples were analyzed by the University of Arkansas System Division of Agriculture Soil Testing and Research Laboratory in Marianna. After removing standards and a check soil measured for quality assurance (14,904), the total number of client samples was 163,728. A total of 52,808 of the submitted soil samples were collected using the field average sampling technique, representing a total of 1,554,093 acres for an average of 29 acres/sample, and had complete data for county, total acres, and soil pH, P, K, and Zn. The cumulative number of samples and acres from information listed in Tables 1 to 4 may vary somewhat because not all samples included SAN, GA, and/or previous crop. The difference of 110,920 samples between the total samples and those with reported acreage were grid samples collected primarily from row-crop fields (106,312) or special or research samples (4,608). The total acreage value does not include the acreage of grid soil samples, but each grid sample likely represents 2.5 acres.

The laboratory first started differentiating between grid and field average soil samples in 2006. The records show that the number of field average soil samples submitted to the laboratory has declined linearly by about 4,204 samples per year (Fig. 1). In contrast, the number of grid soil samples has increased by 18,424 samples/year and now exceeds the total number of field average samples submitted. Despite the decline in field average samples, the total amount of acreage represented has remained above 1.55 million, but the total sampled acres was greatest in 2007 (1.83 million) when the sample number was greatest.

Soil samples from the Bottom Lands and Terraces and Loessial Plains, primarily row-crop areas, represented 47% of the total field average samples and 80% of the total acreage (Table 1). The average number of acres represented by each soil sample (field average samples) ranged from 1 to 64 acres/sample (Table 2). Clients from Craighead (29,168, 62% from two clients); Crittenden (17,376, 98% from two clients); Clay (Corning and Piggott offices, 12,982, 52% from three clients); Mississippi (10,925, 40% from one client); Lawrence (9,874, 92% from one client); and Little River (7,004, 98% from two clients) counties submitted the most soil samples for analyses. The large percentage of the total samples processed through the Craighead, Crittenden, Clay, Mississippi, Lawrence, and Little River county offices were submitted by only a few clients and likely represent commercial grid soil sample collection services.

Soil association numbers show that most samples were taken from soils common to row-crop and pasture production areas (Table 3). The soil associations having the most samples submitted were 44 (Calloway-Henry-Grenada-Calhoun), 4 (Captina-Nixa-Tonti), 45 (Crowley-Stuttgart), 32 (Rilla-Hebert), and 24 (Sharkey-Alligator-Tunica). However, the soil associations representing the largest acreage were 24, 44, 45, 32, and 22 (Foley-Jackport-Crowley) which represented 24.1%, 15.5%, 14.3%, 6.9%, and 6.6% of the total sampled acreage, respectively. Crop codes listed for the field average samples indicate that land used for i) row crop production accounted for 84% of the sampled acreage and 50% of submitted samples, ii) hay and pasture production accounted for 15% of the sampled acreage and 23% of submitted samples, and iii) home lawns and gardens accounted for 1% of sampled acreage and 20% of submitted samples (Table 4). In row-crop producing areas, soil samples are most commonly collected following soybean in the crop rotation. The cumulative acreage soil sampled following soybean represents about 20% of the annual soybean acreage.

The number of soil samples submitted from cool- and warm-season forages managed for hay production, which are primarily from central and western Arkansas, has declined in recent years (Table 5). During this period, nutrient management issues have been common in western Arkansas and many farmers are now required to have nutrient management plans. We initially thought that the need for growers to develop nutrient management plans would have increased soil sample collection and submission. The reason for the lower sample numbers in recent years is currently unknown but could be from a change in production systems.

Soil-Test Data

Information in Tables 6, 7, and 8 pertains to the fertility status of Arkansas soils as categorized by GA, county, and the crop grown prior to collecting field average soil samples (i.e., grid samples not included, except by county), respectively. The soil-test levels and median (Md) nutrient availability index values relate to the potential fertility of a soil, but not necessarily to the productivity of the soil. The median is the value that has an equal number of higher and lower observations and may be a better overall indicator of a soil's fertility status than a mean value. Therefore, it is not practical to compare soil-test values among SAN without knowledge of factors such as location, topography, and cropping system. Likewise, soil-test values among counties cannot be realistically compared without knowledge of the SAN and a profile of the local agricultural production systems. Soil-test results for cropping systems can be carefully compared, however, the specific agricultural production systems often indicate past fertilization practices or may be unique to certain soils that would influence the current soil-test values. The median pH of most soils in Arkansas ranges from 5.5 to 7.3; however, the predominant soil pH range varies among GA (Table 6), county (Table 7), and last crop produced (Table 8).

Table 8 summarizes the percentage of acreage from field-average soil samples that falls within selected soil-test levels (as defined by concentration ranges) and the median concentrations for each of the cropping system categories. Soil-test nutrient availability index values can be categorized into soil-test levels of 'Very Low', 'Low', 'Medium', 'Optimum', and 'Above Optimum'. Among row crops, the lowest median concentrations of P and K occur in soils used for the production of rice and soybean, whereas soils used for cotton production have among the highest median concentrations of P and K. Median soil K availability is lowest in soils used for hay production. The median soil-test K has decreased for several years and suggests that K inputs as fertilizer or manure have declined and K is now likely to be limiting forage yields. The highest median concentrations of P and Zn occur in soils used for non-agricultural purposes (e.g., home garden and landscape/ornamental).

Fertilizer tonnage sold by county (Table 9) and by fertilizer nutrient, formulation, and use (Table 10) illustrates the wide use of inorganic fertilizer predominantly in row-crop production areas. The greatest fertilizer tonnage was sold in Arkansas, Poinsett, and Mississippi counties. Fertilizer tonnage does not account for the use of fresh animal manures or other by-products as a source of nutrients that may be applied to the land. Only processed manures or biosolids (e.g., pelleted poultry litter) are quantified in fertilizer tonnage data and are normally reported in the category of 'Organic'.

PRACTICAL APPLICATIONS

The data presented, or more specific data, can be used in county- or commodity-specific educational programs on soil fertility and fertilization practices. Comparisons of annual soil-test information can also document trends in fertilization practices or areas where nutrient management issues may need to be addressed. Of the soil samples submitted in 2010, 73% of the samples and 98% of the represented acreage had commercial agricultural/farm crop codes. Likewise, 98% of the fertilizer and soil amendment tonnage sold was categorized for farm use. Five counties in eastern Arkansas (Arkansas, Poinsett, Mississippi, Craighead, and Clay) accounted for 32% of the total fertilizer sold.

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Table 1. Sample number and total acreage by geographic area for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2011 through 31 December 2011.

Geographic area	Acres sampled	No. of samples	Acres/ sample
Ozark Highlands - Cherty Limestone and Dolomite	99.346	7,953	13
Ozark Highlands - Sandstone and Limestone	6,333	461	14
Boston Mountains	27,597	2,657	10
Arkansas Valley and Ridges	59.628	5,138	12
Ouachita Mountains	27,516	3,616	8
Bottom Lands and Terraces	659,229	13,700	48
Coastal Plain	35,008	3,862	9
Loessial Plains	393,547	8,647	46
Loessial Hills	14,350	1,287	11
Blackland Prairie	1,237	126	10
Total	1,323,791	47,447	28

Table 2. Sample number (includes grid samples) and total acreage by county for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2011 through 31 December 2011.

County	Acres sampled	No. of samples	Acres/ sample	County	Acres sampled	No. of samples	Acres/ sample
Arkansas, DeWitt	143,594	2,554	56	Lee	327,717	6,517	50
Arkansas, Stuttgart	19,580	817	24	Lincoln	12,130	266	46
Ashley	8,785	572	15	Little River	2,374	7,004	1
Baxter	2,665	455	6	Logan, Booneville	541	117	5
Benton	15,812	1,259	13	Logan, Paris	9,478	449	21
Boone	15,381	832	19	Lonoke	90,937	3,008	30
Bradley	952	114	8	Madison	12,375	720	17
Calhoun	165	39	4	Marion	2,258	176	13
Carroll	20,247	1,024	20	Miller	4,756	398	12
Chicot	31,839	613	52	Mississippi	28,752	10,925	3
Clark	5,078	353	14	Monroe	167,048	2,613	64
Clay, Corning	14,857	5,982	3	Montgomery	1,163	106	11
Clay, Piggott	14,064	7,000	2	Nevada	732	88	8
Cleburne	3,386	371	9	Newton	2,724	168	16
Cleveland	717	1,676	1	Ouachita	597	149	4
Columbia	1,695	247	7	Perry	1,464	152	10
Conway	19,213	572	34	Phillips	15,999	851	19
Craighead	35,366	29,168	1	Pike	3,630	174	21
Crawford	6,683	479	14	Poinsett	36,291	3,533	10
Crittenden	31,743	17,376	2	Polk	9,062	619	15
Cross	57,047	1,032	55	Pope	11,284	790	14
Dallas	260	84	3	Prairie, Des Arc	8,524	250	34
Desha	9,923	2,024	5	Prairie, De Valls Bluff	4,235	114	37
Drew	7,356	466	16	Pulaski	4,774	1,285	4
Faulkner	8,621	1,023	8	Randolph	18,998	2,086	9
Franklin, Charleston	202	30	7	Saline	2,246	507	4
Franklin, Ozark	5,451	342	16	Scott	3,744	232	16
Fulton	4,072	289	14	Searcy	3,619	226	16
Garland	2,381	1,598	2	Sebastian	8,275	738	11
Grant	381	80	5	Sevier	7,454	330	23
Greene	33,688	2,926	12	Sharp	4,890	369	13
Hempstead	7,963	813	10	St. Francis	4,488	6,125	1
Hot Spring	709	199	4	Stone	2,020	284	7
Howard	6,504	381	17	Union	2,291	221	10
Independence	9,319	1,109	8	Van Buren	2,531	283	9
Izard	2,359	223	11	Washington	21,241	2,758	8
Jackson	12,317	6,628	2	White	13,635	1,512	9
Jefferson	56,228	3,589	16	Woodruff	12,941	248	52
Johnson	3,593	365	10	Yell, Danville	9,456	558	17
Lafayette	5,069	201	25	Yell, Dardanelle	123	14	9
Lawrence	52,016	9,874	5				

Table 3. Sample number, total acreage by soil association number (SAN), average acreage per sample, and median soil pH and Mehlich-3 extractable P, K, and Zn values by soil association for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2011 through 31 December 2011.

SAN	Soil association	Acres sampled	No. of samples	Acres/ sample	Median pH	Median P	Median K	Median Zn
1.	Clarksville-Nixa-Noark	22,128	1,378	16	6.2	60	115	5.0
2.	Gepp-Doniphan-Gassville-Agnos	12,288	970	13	6.6	66	137	6.4
3.	Arkana-Moko	24,143	1,367	18	6.1	119	160	10.7
4.	Captina-Nixa-Tonti	37,993	4,041	9	6.3	100	140	8.4
5.	Captina-Doniphan-Gepp	1,942	134	15	6.8	40	131	3.8
6.	Eden-Newnata-Moko	852	63	14	5.9	72	116	4.4
7.	Estate-Portia-Moko	899	66	14	6.0	41	133	4.0
8.	Brockwell-Boden-Portia	5,434	395	14	6.1	34	99	4.5
9.	Linker-Mountainburg-Sidon	5,556	347	16	6.0	54	93	4.6
10.	Enders-Nella-Mountainburg-Steprock	22,041	2,310	10	6.0	77	115	5.9
11.	Falkner-Wrightsville	480	25	19	5.8	48	72	5.4
12.	Leadvale-Taft	29,713	2,511	12	5.9	56	118	5.9
13.	Enders-Mountainburg-Nella-Steprock	4,167	319	13	5.9	53	107	4.7
14.	Spadra-Guthrie-Pickwick	4,712	250	19	5.7	47	113	5.1
15.	Linker-Mountainburg	20,556	2,033	10	5.9	64	114	5.4
16.	Carnasaw-Pirum-Clebit	6,489	858	8	5.9	77	99	7.2
17.	Kenn-Ceda-Avilla	6,350	409	16	5.7	99	115	6.6
18.	Carnasaw-Sherwood-Bismarck	11,138	2,079	5	5.8	88	119	6.0
19.	Carnasaw-Bismarck	965	81	12	5.7	77	108	6.6
20.	Leadvale-Taft	533	46	12	5.5	25	92	3.0
21.	Spadra-Pickwick	2,041	143	14	5.7	60	93	5.8
22.	Foley-Jackport-Crowley	87,502	2,578	34	6.3	25	103	3.2
23.	Kobel	8,102	211	38	5.9	28	101	3.4
24.	Sharkey-Alligator-Tunica	318,871	2,954	108	6.1	45	220	3.5
25.	Dundee-Bosket-Dubbs	45,016	1,425	32	6.3	49	147	3.5
26.	Amagon-Dundee	26,670	946	28	6.3	57	142	4.6
27.	Sharkey-Steele	6,243	150	42	6.6	52	190	5.3
28.	Commerce-Sharkey-Crevasse-Robinsonville	14,603	375	39	6.8	45	205	4.4
29.	Perry-Portland	42,858	1,137	38	6.5	45	168	3.0
30.	Crevasse-Bruno-Oklared	295	20	15	5.7	183	136	15.2
31.	Roxana-Dardanelle-Bruno-Roellen	10,101	295	34	6.5	35	127	4.2
32.	Rilla-Hebert	90,993	3,264	28	6.4	46	137	3.1
33.	Billyhaw-Perry	2,969	86	35	6.5	35	257	3.2
34.	Severn-Oklared	3,203	103	31	5.9	46	127	3.8
35.	Adaton	317	16	20	5.7	140	148	9.0
36.	Wrightsville-Louin-Acadia	1,091	107	10	5.4	52	107	3.7
37.	Muskogee-Wrightsville-McKamie	395	33	12	5.4	70	184	10.1
38.	Amy-Smithton-Pheba	1,038	163	6	5.8	55	90	4.6
39.	Darco-Briley-Smithdale	168	13	13	5.4	43	79	6.1
40.	Pheba-Amy-Savannah	1,272	112	11	5.7	56	99	4.3
41.	Smithdale-Sacul-Savannah-Saffell	11,124	1,241	9	5.8	83	102	5.6
42.	Sacul-Smithdale-Sawyer	11,956	1,910	6	6.0	46	81	4.6
43.	Guyton-Ouachita-Sardis	9,450	423	22	5.6	90	109	7.8
44.	Calloway-Henry-Grenada-Calhoun	204,837	5,079	40	6.9	30	98	3.1
45.	Crowley-Stuttgart	188,710	3,568	53	6.6	28	97	3.4
46.	Loring	1,930	62	31	5.6	41	85	3.6
47.	Loring-Memphis	11,678	1,185	10	6.4	46	120	4.2
48.	Brandon	742	40	19	6.5	41	136	4.1
49.	Oktibbeha-Sumter	1,237	126	10	5.9	38	114	4.4
	Sum or Average	1,323,791	47,447	28	6.0	59	125	5.3

Table 4. Sample number and total acreage by previous crop for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2011 through 31 December 2011.

Crop	Acres sampled	No. of samples	Acres/ sample
Corn	98,533	1,951	51
Cotton	227,693	4,041	56
Grain sorghum, non-irrigated	1,490	29	51
Grain sorghum, irrigated	1,902	61	31
Rice	155,944	3,584	44
Soybean	623,962	12,980	48
Wheat	16,138	383	42
Cool-season grass hay	8,660	513	7
Native warm-season grass hay	3,436	219	16
Warm-season grass hay	39,479	1,911	21
Pasture, all categories	146,097	7,796	19
Home garden	6,763	4,908	1
Turf	7,807	1,509	5
Home lawn	5,113	4,368	1
Small fruit	745	519	1
Ornamental	2,093	1,217	2
Sum or average	1,345,855	45,989	29

Table 5. Number of soil samples, following cool- or warm-season forage managed for hay production, for selected counties submitted to the Soil Testing and Research Laboratory in Marianna from 2006-2011.

		Year					
County	Forage type	2006	2007	2008	2009	2010	2011
		(No. of samples)					
Benton	Cool-season	1,215	122	5	46	66	67
Boone	Cool-season	112	174	11	51	17	56
Washington	Cool-season	750	846	14	89	98	75
Benton	Warm-season	195	140	136	120	85	127
Conway	Warm-season	195	170	88	148	169	123
Washington	Warm-season	563	589	310	158	142	90

Table 6. Soil-test data (% of sampled acres) and median (Md) values by geographic area for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2011 through 31 December 2011.

	Soil pH[a]						Mehlich-3 soil P[b] (ppm)						Mehlich-3 soil K[b] (ppm)						Mehlich-3 soil Zn[b] (ppm)					
Geographic area	<5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md[c]	<16	16-25	26-35	36-50	>50	Md	<61	61-90	91-130	131-175	>175	Md	<1.6	1.6-3.0	3.1-4.0	4.1-8.0	>8.0	Md
	---(% of sampled acreage) ---						--(% of sampled acreage) --					(ppm)	-- (% of sampled acreage) ---					(ppm)	---- (% of sampled acreage) ----					(ppm)
Ozark Highlands	8	17	25	28	22	6.3	5	8	9	11	67	83	9	16	21	19	35	138	3	15	11	25	46	7.6
Ozark Highlands	10	23	25	24	18	6.1	19	20	11	11	39	36	18	23	25	16	18	102	7	27	15	26	25	4.4
Boston Mountains	16	23	25	24	12	6.0	6	9	9	12	64	75	15	22	22	15	26	113	6	19	12	28	35	5.8
Arkansas Valley and Ridges	22	25	24	19	10	5.9	11	11	11	12	55	58	15	20	24	17	24	115	6	20	12	28	34	5.6
Ouachita Mountains	26	27	24	18	5	5.8	6	8	9	10	67	85	16	21	24	16	23	111	4	16	11	29	40	6.4
Bottom Lands and Terraces	9	15	25	34	17	6.3	8	14	17	25	36	42	5	14	23	20	38	145	8	35	21	30	6	3.5
Coastal Plain	28	24	19	18	11	5.8	18	10	8	9	55	60	29	22	19	12	18	90	10	24	10	21	35	5.2
Loessial Plains	7	11	15	27	40	6.8	14	27	22	18	19	29	10	33	32	13	12	98	11	38	17	26	8	3.2
Loessial Hills	15	17	17	29	22	6.3	11	15	13	15	35	46	10	19	29	20	22	120	5	28	19	28	20	4.1
Blackland Prairie	25	26	13	14	22	5.9	10	12	24	12	42	38	16	21	19	15	29	114	7	21	19	22	31	4.4
Average	17	21	21	24	17	6.1	11	13	13	14	49	55	14	21	24	16	25	115	7	24	15	26	28	5.0

[a] Analysis by electrode in 1:2 soil volume:deionized water volume.
[b] Analysis by ICAP in 1:10 soil volume:Mehlich-3 volume.
[c] Md = median.

Table 7. Soil test data (% of sampled acres) and median (Md) values by county for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2011 through 31 December 2011.

County	Soil pH[a]						Mehlich-3 soil P[b] (ppm)						Mehlich-3 soil K[b] (ppm)						Mehlich-3 soil Zn[b] (ppm)					
	<5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md[c]	<16	16-25	26-35	36-50	>50	Md	<61	61-90	91-130	131-175	>175	Md	<1.6	1.6-3.0	3.1-4.0	4.1-8.0	>8.0	Md
	---(% of sampled acreage) ---						--(% of sampled acreage) --					(ppm)	-- (% of sampled acreage)---					(ppm)	---- (% of sampled acreage) ----					(ppm)
Arkansas, DeWitt	5	9	12	21	53	7.1	14	28	27	19	12	28	6	38	35	11	10	95	8	28	21	39	4	3.9
Arkansas, Stuttgart	12	13	19	31	25	6.4	32	33	19	9	7	21	8	49	28	9	6	86	23	43	15	16	3	2.3
Ashley	12	12	16	31	29	6.5	17	15	13	19	36	41	18	19	26	19	18	111	18	37	11	23	11	2.8
Baxter	4	7	9	20	60	7.3	5	7	8	8	72	103	5	8	22	20	45	163	1	7	4	20	68	13.3
Benton	12	19	24	29	16	6.2	4	5	6	8	77	130	10	13	19	20	38	146	1	10	9	26	54	9.7
Boone	6	16	31	30	17	6.2	3	12	10	15	60	65	13	18	20	16	33	127	3	18	15	31	33	5.8
Bradley	20	10	17	19	34	6.4	6	9	4	6	75	146	19	18	13	19	31	128	4	14	11	17	54	9.4
Calhoun	28	23	28	15	6	5.7	13	10	5	13	59	70	26	33	18	13	10	79	8	28	10	15	39	5.5
Carroll	7	21	34	24	14	6.1	1	3	3	7	86	162	5	10	14	16	55	193	1	4	5	21	69	14.1
Chicot	5	8	18	39	30	6.6	6	15	13	22	44	48	5	10	18	20	47	170	17	41	18	22	2	2.8
Clark	28	30	20	15	7	5.7	17	10	6	5	62	84	24	20	26	13	17	100	11	23	13	24	29	4.5
Clay, Corning	7	14	26	40	13	6.3	13	25	23	22	17	30	12	29	34	17	8	99	11	24	12	39	14	4.6
Clay, Piggott	10	13	18	38	21	6.5	7	10	13	20	50	51	7	16	24	22	31	137	11	39	21	28	1	3.2
Cleburne	25	24	21	24	6	5.8	10	11	12	15	52	55	19	22	23	17	19	102	14	24	12	25	25	4.2
Cleveland	8	16	21	30	25	6.4	1	4	7	18	70	66	3	8	16	21	52	183	11	43	20	26	0	3.0
Columbia	40	23	20	13	4	5.6	19	11	9	7	54	55	30	26	17	11	16	84	19	20	9	25	27	4.6
Conway	29	20	17	22	12	5.9	17	19	15	11	38	34	20	24	19	13	24	98	9	25	13	32	21	4.5
Craighead	8	12	18	34	28	6.5	10	17	17	21	35	39	7	19	26	20	28	128	6	34	23	32	5	3.6
Crawford	13	23	23	24	17	6.1	12	9	10	15	54	55	20	18	22	19	21	112	3	17	16	29	35	5.6
Crittenden	10	13	21	36	20	6.4	6	15	20	27	32	41	3	10	19	19	49	172	9	34	24	33	0	3.5
Cross	5	7	11	23	54	7.1	14	29	21	15	21	28	8	33	25	13	21	101	8	36	20	27	9	3.5
Dallas	27	24	26	18	5	5.8	20	11	12	6	51	51	29	18	30	11	12	94	16	21	13	19	31	4.2
Desha	4	9	25	42	20	6.5	2	6	13	28	51	51	2	14	27	26	31	141	8	37	24	31	0	3.4
Drew	21	24	26	25	4	5.9	16	16	16	13	39	38	9	22	28	17	24	115	11	25	13	21	30	4.4
Faulkner	24	21	21	25	9	6.0	16	18	15	14	37	36	14	26	27	16	17	104	11	29	13	28	19	4.0
Franklin, Charleston	17	17	23	23	20	6.1	23	10	0	20	47	49	17	10	20	20	33	132	7	10	10	43	30	6.3
Franklin, Ozark	27	37	26	10	0	5.7	4	11	9	9	67	89	14	15	16	22	33	139	6	14	5	29	46	7.7
Fulton	8	19	23	25	25	6.3	8	11	16	20	45	44	10	21	28	17	24	117	5	34	16	27	18	3.8
Garland	24	24	24	22	6	5.9	5	7	8	14	66	75	10	20	25	19	26	122	4	18	13	31	34	5.7
Grant	39	29	19	8	5	5.5	25	4	13	5	53	59	30	21	15	13	21	89	16	16	8	31	29	5.2
Greene	12	20	25	30	13	6.1	23	28	17	16	16	25	13	23	30	19	15	108	10	47	21	20	2	2.9
Hempstead	19	27	16	24	14	6.0	43	15	7	5	30	19	46	17	12	9	16	66	14	32	10	13	31	3.5
Hot Spring	33	23	24	14	6	5.7	19	12	6	10	53	55	29	23	20	10	18	86	18	22	7	24	29	4.4
Howard	38	30	20	11	1	5.6	6	4	8	8	74	132	14	15	19	15	37	137	3	12	9	23	53	8.7
Independence	10	15	21	27	27	6.4	13	16	19	18	34	37	17	28	27	13	15	98	9	39	15	24	13	3.3
Izard	11	22	29	25	13	6.1	15	16	11	18	40	40	22	36	24	9	9	83	9	41	16	20	14	3.2
Jackson	14	20	25	27	14	6.1	25	21	15	16	23	28	13	26	29	18	14	103	12	44	19	23	2	2.9
Jefferson	9	15	24	35	17	6.3	6	15	19	27	33	40	7	19	27	21	26	124	15	45	21	17	2	2.8
Johnson	25	29	20	18	8	5.7	9	8	12	14	57	57	8	15	27	22	28	129	5	24	11	32	28	5.0
Lafayette	31	17	18	14	20	5.9	8	12	11	17	52	52	13	9	22	18	38	144	10	36	14	16	24	3.5
Lawrence	7	16	26	36	15	6.3	20	32	23	16	9	25	18	29	26	16	11	95	8	46	22	22	2	3.0
Lee	8	13	22	37	20	6.4	2	11	20	31	36	44	2	12	29	23	34	141	16	48	16	20	0	2.5
Lincoln	15	13	21	35	16	6.3	9	5	14	22	50	51	7	11	15	17	50	179	8	21	20	36	15	4.3
Little River	9	13	18	23	37	6.6	9	18	18	20	35	39	1	5	18	21	55	184	19	43	19	19	0	2.6

continued

Table 7. Continued.

County	Soil pH[a]						Mehlich-3 soil P[b] (ppm)						Mehlich-3 soil K[b] (ppm)						Mehlich-3 soil Zn[b] (ppm)					
	<5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md[c]	<16	16-25	26-35	36-50	>50	Md	<61	61-90	91-130	131-175	>175	Md	<1.6	1.6-3.0	3.1-4.0	4.1-8.0	>8.0	Md
	---(% of sampled acreage) ---						--(% of sampled acreage) --					(ppm)	-- (% of sampled acreage)---					(ppm)	----(% of sampled acreage)----					(ppm)
Logan, Booneville	21	29	30	13	7	5.8	22	12	11	7	48	49	16	34	21	14	15	90	3	34	10	24	29	4.5
Logan, Paris	17	39	29	13	2	5.8	8	8	8	11	65	71	20	18	14	15	33	126	4	13	13	33	37	6.3
Lonoke	14	18	25	32	11	6.2	13	23	19	19	26	32	10	27	32	15	16	104	24	47	13	13	3	2.3
Madison	15	28	30	24	3	6.0	5	7	6	9	73	105	10	19	19	17	35	133	2	14	11	26	47	7.7
Marion	2	10	22	31	35	6.6	11	14	14	13	48	45	8	22	24	17	29	121	6	17	13	22	42	6.3
Miller	27	24	22	16	11	5.8	11	13	11	14	51	51	27	23	23	15	12	90	11	24	12	22	31	4.6
Mississippi	4	9	21	45	21	6.5	1	2	6	17	74	64	1	3	17	32	47	174	1	23	28	42	6	4.2
Monroe	4	10	16	27	43	6.8	16	22	19	22	21	32	10	25	30	21	14	111	10	39	20	29	2	3.2
Montgomery	28	26	20	18	8	5.8	3	5	7	8	77	114	20	20	24	16	20	103	1	9	13	36	41	6.1
Nevada	22	27	27	16	8	5.8	3	9	13	7	68	75	10	22	22	13	33	120	6	24	15	23	32	5.6
Newton	13	26	33	19	9	6.0	11	20	16	11	42	41	22	19	20	14	25	104	13	31	14	29	13	3.7
Ouachita	32	22	15	26	5	5.8	13	3	8	8	68	82	34	18	18	14	16	87	12	22	9	28	29	4.8
Perry	26	26	31	13	4	5.8	13	13	15	9	50	50	25	24	18	13	20	93	4	22	13	30	31	5.1
Phillips	3	9	13	39	36	6.8	2	11	20	41	26	44	3	20	43	18	16	114	18	47	1	15	19	2.5
Pike	34	36	20	10	0	5.5	6	5	7	5	77	176	35	20	17	14	14	83	4	18	8	25	45	7.2
Poinsett	4	11	15	30	40	6.8	18	28	20	18	16	27	12	36	26	13	13	92	6	24	15	32	23	4.7
Polk	24	34	23	16	3	5.7	3	5	7	6	79	153	18	19	21	14	28	118	4	15	7	26	48	8.2
Pope	20	25	27	20	8	5.9	11	11	9	12	57	63	13	19	25	17	26	119	7	24	14	26	29	4.9
Prairie, Des Arc	11	15	26	30	18	6.3	16	34	24	15	11	25	6	31	41	13	9	99	18	36	14	23	9	2.8
Prairie, De Valls Bluff	11	18	27	31	13	6.2	13	31	18	11	27	27	1	33	29	12	25	115	11	30	17	21	21	3.6
Pulaski	28	16	18	20	18	6.0	9	8	10	10	63	72	14	23	27	16	20	107	7	17	10	25	41	6.7
Randolph	7	12	26	37	18	6.3	18	25	21	18	18	29	9	26	33	18	14	108	10	37	19	28	6	3.3
Saline	28	19	17	23	13	5.9	9	9	12	12	58	64	22	20	23	16	19	107	8	23	13	21	35	5.1
Scott	24	22	31	21	2	5.9	12	12	16	7	53	58	29	13	17	18	23	106	4	19	15	30	32	5.3
Searcy	20	29	23	20	8	5.9	5	14	15	19	47	48	7	31	26	16	20	107	9	25	20	28	18	4.0
Sebastian	17	24	22	16	21	6.0	8	10	8	9	65	77	10	18	21	21	30	135	1	10	11	26	52	9.2
Sevier	38	35	21	6	0	5.5	11	8	7	9	65	102	23	18	14	12	33	115	6	19	9	20	8	8.1
Sharp	14	17	22	21	26	6.3	11	15	10	12	52	55	14	15	19	21	31	135	6	25	16	25	28	4.7
St. Francis	6	10	21	3	24	6.5	5	11	13	24	47	49	2	8	15	15	60	209	20	47	16	17	0	2.4
Stone	17	22	27	20	14	6.0	3	7	10	17	63	62	11	18	30	21	20	113	6	21	18	35	20	4.5
Union	32	23	20	18	7	5.8	7	9	8	10	66	84	24	29	23	10	14	86	5	16	8	25	46	7.4
Van Buren	19	21	29	24	7	6.0	8	16	9	14	53	52	16	22	24	17	21	112	13	25	12	24	26	4.2
Washington	7	16	23	28	26	6.4	5	8	10	10	67	89	7	15	24	21	33	137	3	11	11	27	48	8.1
White	15	20	23	27	15	6.1	8	11	11	12	58	64	17	24	25	14	20	103	6	22	10	29	33	5.8
Woodruff	11	16	21	32	20	6.3	17	22	23	17	21	30	14	37	29	12	8	90	5	38	22	31	4	3.4
Yell, Danville	27	36	25	12	0	5.6	13	13	10	9	55	64	14	24	26	12	24	108	3	22	13	27	35	5.9
Yell, Dardanelle	14	21	43	14	8	5.9	0	0	0	21	79	124	7	21	21	29	22	119	0	14	7	7	72	10.1
Average	17	20	23	24	16	6.1	11	13	13	14	49	61	14	21	23	17	25	118	9	27	14	26	24	5.0

[a] Analysis by electrode in 1:2 soil weight:deionized water volume.
[b] Analysis by ICAP in 1:10 soil weight:Mehlich-3 volume.
[c] Md = median.

Table 8. Soil-test data (% of sampled acres) and median (Md) values by previous crop for soil samples submitted to the Soil Testing and Research Laboratory in Marianna from 1 January 2011 through 31 December 2011.

	Soil pH[a]						Mehlich-3 soil P[b] (ppm)						Mehlich-3 soil K[b] (ppm)						Mehlich-3 soil Zn[b] (ppm)					
Geographic area	<5.4	5.4-5.7	5.8-6.2	6.3-6.9	>6.9	Md[c]	<16	16-25	26-35	36-50	>50	Md	<61	61-90	91-130	131-175	>175	Md	<1.6	1.6-3.0	3.1-4.0	4.1-8.0	>8.0	Md
	---(% of sampled acreage) ---						--(% of sampled acreage) --					(ppm)	-- (% of sampled acreage)---					(ppm)	---- (% of sampled acreage) ----					(ppm)
Corn	7	13	22	38	20	6.4	4	11	18	30	37	43	4	17	32	21	26	126	13	36	19	28	4	3.2
Cotton	7	11	26	41	15	6.4	1	5	15	29	50	51	1	8	25	29	37	154	10	40	21	28	1	3.2
Grain sorghum, non-irrigated	21	17	21	31	10	5.9	14	17	21	24	24	32	0	17	28	0	55	197	10	31	10	45	4	3.8
Grain sorghum, irrigated	8	16	10	31	35	6.6	3	16	23	26	32	41	8	16	23	15	38	137	7	38	10	36	9	3.8
Rice	8	14	21	31	26	6.5	22	31	20	17	10	25	8	24	27	16	25	115	8	43	21	25	3	3.1
Soybean	6	12	19	30	33	6.6	12	23	22	22	21	32	8	29	30	14	19	105	10	39	20	28	3	3.2
Wheat	24	23	21	20	12	6.0	5	15	15	23	42	44	6	25	35	14	20	110	12	38	17	27	6	3.2
Cool-season grass hay	12	23	30	28	7	6.0	7	9	11	17	56	56	24	26	20	13	17	91	5	29	12	29	25	4.6
Native warm-season grass hay	35	29	18	16	2	5.6	20	16	16	14	34	35	22	30	22	13	13	89	12	28	14	32	14	4.0
Warm-season grass hay	23	28	24	23	2	5.8	11	11	12	10	56	61	27	25	21	13	14	88	10	25	11	22	32	4.7
Pasture, all categories	20	30	28	19	3	5.8	13	11	10	10	56	62	19	18	20	15	28	116	7	21	11	24	37	5.7
Home garden	9	12	16	24	39	6.7	4	5	5	7	79	141	6	12	18	18	46	164	3	10	7	20	60	11.8
Turf	10	12	25	35	18	6.4	3	5	7	12	73	80	17	22	22	16	23	110	3	16	10	35	36	6.4
Home lawn	27	20	20	21	12	5.9	7	11	12	15	55	56	8	19	31	22	20	120	3	19	17	38	23	5.1
Small fruit	26	19	18	23	14	6.0	5	7	9	11	68	78	11	17	28	16	28	121	5	15	11	21	48	8.2
Ornamental	12	11	16	23	38	6.6	9	7	10	10	64	74	13	21	25	18	23	115	4	10	7	22	57	10.2
Average	16	18	21	27	18	6.2	9	13	14	17	47	57	11	20	25	16	28	122	8	27	14	29	22	5.3

[a] Analysis by electrode in 1:2 soil weight:deionized water volume.
[b] Analysis by ICAP in 1:10 soil weight:Mehlich-3 volume.
[c] Md = median.

Table 9. Fertilizer tonnage sold in Arkansas counties from 1 July 2011 through 30 June 2012[a].

County	Fertilizer sold	County	Fertilizer sold	County	Fertilizer sold
	(tons)		(tons)		(tons)
Arkansas	92,261	Garland	2,132	Newton	492
Ashley	17,442	Grant	958	Ouachita	96
Baxter	1,786	Greene	38,669	Perry	765
Benton	14,120	Hempstead	2,154	Phillips	58,706
Boone	2,822	Hot Spring	759	Pike	522
Bradley	627	Howard	646	Poinsett	73,518
Calhoun	60	Independence	8,036	Polk	1,211
Carroll	2,355	Izard	1,199	Pope	1,936
Chicot	40,159	Jackson	27,717	Prairie	29,018
Clark	812	Jefferson	33,106	Pulaski	18,072
Clay	68,925	Johnson	757	Randolph	20,621
Cleburne	1,496	Lafayette	6,836	Saline	1,497
Cleveland	24	Lawrence	33,110	Scott	296
Columbia	1,237	Lee	30,839	Searcy	1,657
Conway	5,609	Lincoln	13,441	Sebastian	3,296
Craighead	69,317	Little River	2,337	Sevier	947
Crawford	4,750	Logan	807	Sharp	1,180
Crittenden	24,833	Lonoke	58,089	St. Francis	39,675
Cross	42,498	Madison	3,572	Stone	1,096
Dallas	20	Marion	1,685	Union	908
Desha	37,220	Miller	9,354	Van Buren	6,963
Drew	10,665	Mississippi	72,087	Washington	4,823
Faulkner	3,994	Monroe	45,422	White	27,696
Franklin	1,338	Montgomery	388	Woodruff	28,203
Fulton	1,267	Nevada	622	Yell	510

[a] Arkansas Distribution of Fertilizer Sales by County, 1 July 2011 to 30 June 2012, Arkansas State Plant Board, Division of Feed and Fertilizer, Little Rock, Ark., and University of Arkansas System Division of Agriculture, Arkansas Agricultural Experiment Station, Fayetteville, Ark.

Table 10. Fertilizer nutrient, formulation, and use category sold in Arkansas from 1 July 2011 through 30 June 2012[a].

	Container			Use		
Fertilizer	Bag	Bulk	Liquid	Farm	Non-farm	Totals
	(tons)					
Multi-nutrient	60,031	298,866	8,737	354,771	12,863	367,634
Nitrogen	4,804	538,407	105,699	641,013	7,897	648,910
Phosphate	558	32,531	13	32,580	522	33,102
Potash	379	89,945	98	89,018	1,405	90,423
Organic	28	160	0	161	28	189
Micronutrient	1,447	736	108	2,273	17	2,290
Lime	562	3,958	10	4,317	212	4,529
Miscellaneous	5,381	6,326	5,282	16,529	460	16,989
Totals	73,190	970,929	119,947	1,140,662	23,404	1,164,066

[a] Arkansas Distribution of Fertilizer Sales by County, 1 July 2011 to 30 June 2012, Arkansas State Plant Board, Division of Feed and Fertilizer, Little Rock, Ark., and University of Arkansas System Division of Agriculture, Arkansas Agricultural Experiment Station, Fayetteville, Ark.

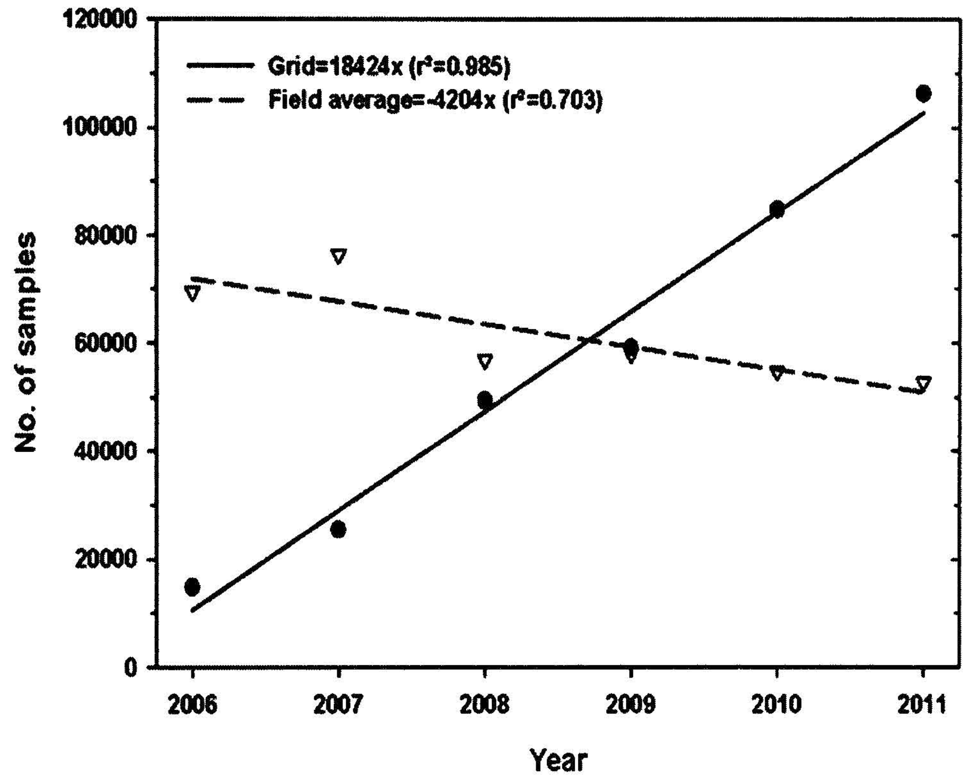

Fig. 1. Total number of soil samples and collection method submitted to the Soil Testing and Research Laboratory in Marianna from 2006-2011.

Influence of Poultry Litter on N-ST*R Soil-test Values During a Laboratory Incubation

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Rice (*Oryza sativa* L.), is grown on approximately 1.2 million acres in Arkansas annually, making Arkansas the leading rice-producing state in the U.S. Concurrently, poultry litter (PL) is one of the most nutrient-rich soil amendments and is applied to a large number of row-crop acres each year in Arkansas. Poultry litter is typically applied to satisfy phosphorus (P) and potassium (K) recommendations; however, a study conducted by Golden et al. (2006) indicated that about 25% of the total nitrogen (TN) applied as PL was recovered by the rice crop. Most of the nitrogen (N) in PL is found in the organic form, ~90%, with the remaining 10% of the TN found in PL as inorganic-N, mainly in the form of NH_4-N. With mineralization catalyzed by microbial activity, the rate in which the organic-N fraction of PL is mineralized can be rapid and is influenced by litter characteristics and soil temperature, moisture, and texture. Laboratory incubation research conducted by Diaz et al. (2008) and Gordon (2011) indicated soil NH_4-N concentrations following a PL application peak within 1 week.

The most recent advancement in predicting N fertilizer needs for rice production in Arkansas was the correlation and calibration of the Nitrogen-Soil Test for Rice (N-ST*R) developed by Roberts et al. (2011). This is a site-specific soil-based N test that predicts potentially mineralizable soil-N (e.g., amino sugars, amino acids, and NH_4) as alkaline hydrolyzable-N (AH-N). Alkaline hydrolyzable-N is used to determine N fertilizer needs for rice on silt loam soils and uses the direct steam distillation (DSD) method of determination (Bushong et al., 2008). The N-ST*R has been released for use in Arkansas to predict field-specific N requirements; however, there has been little research concerning the effect of PL applications on N-ST*R soil-test values. Rice producers are applying PL and using N-ST*R, so it is important to understand how PL rate and application time influence N-ST*R soil-test values. Therefore, the objective of this research was to quantify PL influences on N-ST*R soil-test values and determine the minimum time following a PL application to collect soil samples for N fertilizer recommendations.

PROCEDURES

To evaluate the effects of PL source on N-ST*R soil-test values using the DSD, a 60 day aerobic laboratory incubation was conducted. Treatments for this experiment included an untreated control (no-PL) and five sources of PL (Table 1), arranged in a randomized complete block design with three replications. Four of the PL sources used in this incubation were collected from fresh litter samples from northwest Arkansas sent to the University of Arkansas System Division of Agriculture Diagnostic Laboratory for nutrient analysis. The fifth PL sample was pelletized poultry litter (PPL). Each of the four fresh PL sources was blended and stored in sealable bags. Soil used in the incubation was collected from the University of Arkansas Pine Tree Research Station (Calhoun silt loam, pH 7.9) from the top 6-in. of the soil surface, dried in a greenhouse, and crushed to pass a 2-mm sieve.

Incubations were performed in 100-mL specimen cups filled with 100 g of soil. Soil was moistened and placed in the incubation chamber at 23 °C (73 °F) for a 10 day preincubation period. A -85 kPa matric potential (20% gravimetric moisture) was maintained throughout the duration of the incubation using deionized water. Immediately after the preincubation, PL was weighed (0.1612 to 0.3701 g PL/100 g soil; to the nearest 0.0001 g) to supply 148 lb N/acre (equivalent to 2 ton/acre of the PPL) and added to the appropriate cup and mixed. Specimen cups with the amended PL were loosely covered with plastic wrap and returned to the incubation chamber at a constant temperature of 23 °C. Extractions to quantify AH-N were performed at 0, 3, 7, 11, 15, 24, 33, 42, 51, and 60 days after initiation of the incubation. At each extraction time, specific specimen cups were removed from the incubator and soil was transferred into soil boxes, dried at 55 °C, crushed to pass a 2-mm sieve, and sent to the University of Arkansas N-ST*R Soil Testing Lab to analyze AH-N using the DSD method outlined by Bushong et al. (2008).

Statistical analyses were carried out using JMP PRO 9.0 (SAS Institute, Inc., Cary, N.C.). Data was analyzed as a split-plot design with PL source as the whole-plot factor and extraction time as the split-plot factor. Means were calculated by averaging the replicates at each extraction time. Means were separated using the least significant difference (LSD) test, assessing significance at $P < 0.05$.

RESULTS AND DISCUSSION

There was a significant influence on AH-N values as a result of PL application, which was further influenced by the two-way interaction of PL source and extraction time ($P < 0.0001$). This interaction is a result of significant differences in the AH-N values among litter sources for the 0- and 3-day extraction times. Substantial fluctuations in AH-N were observed within the first 7 days and the AH-N values peaked within the first 3 days. Similar results were observed for an incubation experiment using PL and a Calhoun silt loam soil in Arkansas conducted by Gordon (2011), who reported a peak in NH_4-N concentrations within the first 7 days after PL was applied. Significant differences among PL sources were observed only within the first 3 days of our incubation (Fig. 1).

Alkaline hydrolyzable-N stabilized with 85 to 90 mg N/kg soil after 11 days into the incubation for all PL sources, with no significant changes in AH-N for all fresh PL sources following the 11-day extraction (Fig. 2a, b, c, and d). There was a significant increase in AH-N for the PPL at the 33-day extraction (Fig. 2e); however, this increase was not a significant amount when determining N fertilizer recommendations using N-ST*R. Previous research has shown PL mineralization can be separated into two distinct phases including a rapid initial flux of N mineralization followed by a slower phase (Hadas et al., 1983). Correspondingly, this experiment displays two phases of N mineralization with the initial rapid phase occurring in the first week trailed by a slower rate of mineralization which is relatively constant (Fig. 1). The AH-N concentrations followed similar trends as soil NH_4-N concentrations following a PL application as shown by Hadas et al. (1983) who reported that soil NH_4-N reached a maximal concentration within the first week followed by a substantial decrease.

The fresh-2, -3, and -4 litters contained greater initial inorganic N concentrations than the fresh-1 and PPL (data not shown), resulting in an immediate decrease in AH-N values from the establishment of the incubation until reaching a plateau at the 11-day extraction. However, the fresh-1 and PPL sources had greater proportions of N in the organic form, resulting in an initial increase in AH-N from the 0- to 3-day extractions followed by a significant decrease. The AH-N in all litter amended soils reached a plateau at the 11-day extraction time, with a steady mineralization rate (Fig. 1). Also, PL sources that displayed delays in their peak AH-N concentrations (PPL and fresh-1) had low (<20%) initial moisture contents compared to the other litter sources (Table 1). The higher moisture content of the fresh-2, -3, and -4 litter sources potentially could have been the reason why we observed no delay in mineralization at the start of the incubation. The dry state of the litter-1 and PPL may have delayed microbial activity.

If N recommendations were based on AH-N values within the first week following the PL application, the resulting N recommendation from N-ST*R would have been underestimated and could have been as low as 84 lb N/acre (156 mg N/kg soil; Roberts et al., 2011). However, the lowest N rate recommendation from N-ST*R from 7 to 60 days after the PL application was 126 lb N/acre (93 mg N/kg soil). Our results show that the DSD method quantifies AH-N in the soil and PL indicating the importance of soil sampling time for N recommendations using N-ST*R following a PL application.

PRACTICAL APPLICATIONS

Information relating the influence of PL on N-ST*R soil-test values across time allow us to ensure that the proper N recommendation is determined using N-ST*R following a PL application. The results of this study demonstrate the ability to design soil sampling protocols, recommending that producers applying PL need to wait at least 11 days following a PL application before collecting soil samples for N recommendations using N-ST*R.

ACKNOWLEDGMENTS

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Table 1. Characteristics of the poultry litter utilized in the 60-day incubation study.

Treatment	Litter type	Bedding material	Animal type	On "as-is" basis Total N	Total C	Moisture
				----------(%)----------		
PPL[a]	pelletized	none given	none given	3.70	30.24	11.40
fresh-1	fresh	rice hull	cornish hen	4.56	32.27	16.70
fresh-2	fresh	shavings/sawdust	pullet	2.54	20.62	29.09
fresh-3	fresh	none given	broiler	3.33	22.03	43.08
fresh-4	fresh	rice hull/shavings	broiler	1.99	29.21	27.40

[a] PPL, pelleted poultry litter obtained from Perdue AgriRecycle (Seaford, Del.).

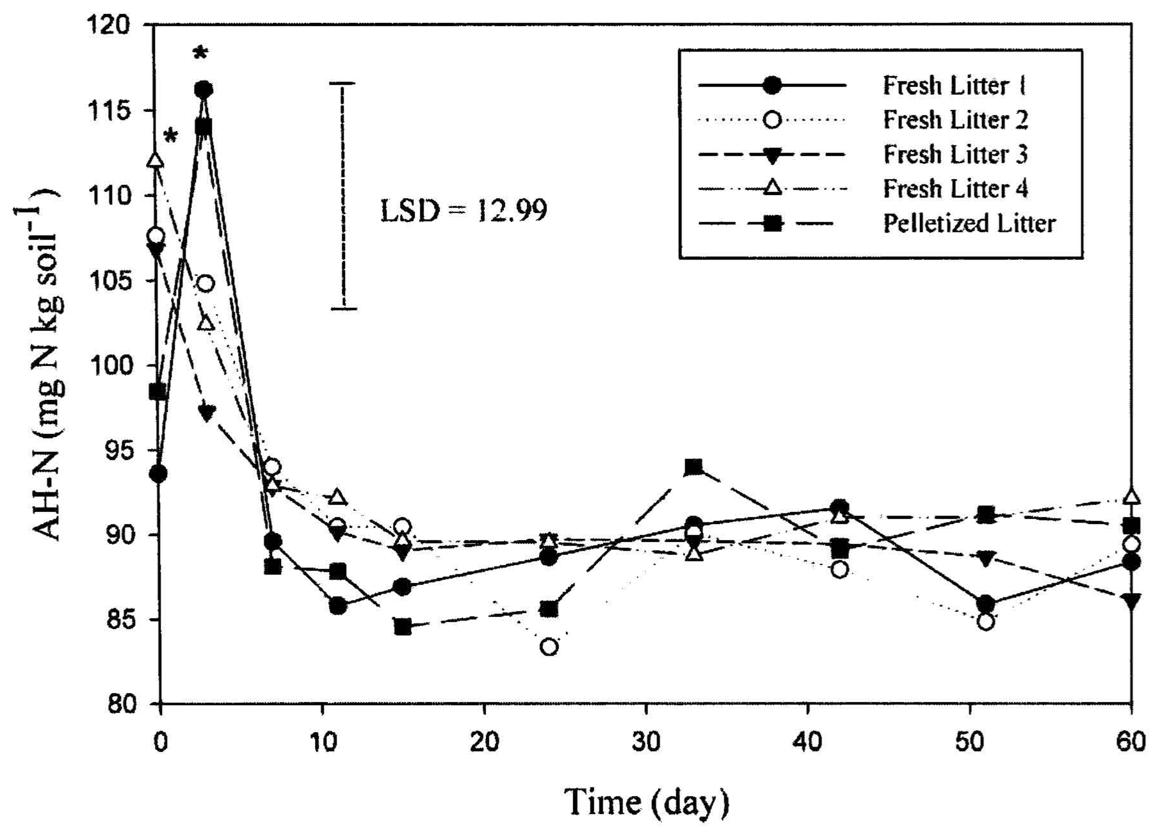

Fig. 1. Influence of poultry litter source and sample time on alkaline hydrolyzable-N (AH-N) to compare litter sources within the same extraction time. The * indicates a significant difference among litter sources within an extraction time at the *P* < 0.05 level.

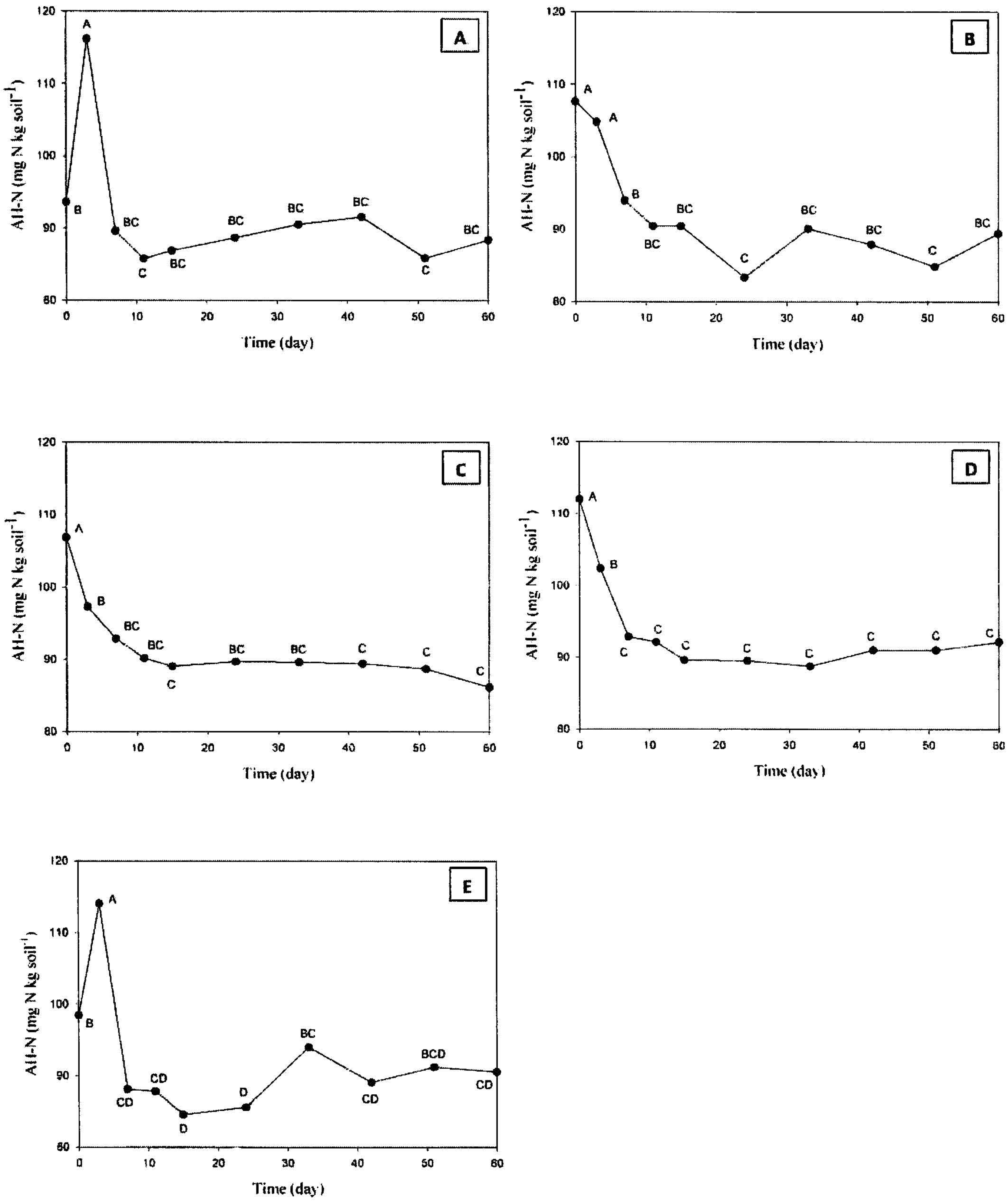

Fig. 2. Influence of poultry litter (PL) source and sample time on alkaline hydrolyzable-N (AH-N) for a) fresh litter-1 b) fresh litter-2 c) fresh litter-3 d) fresh litter-4 and e) pelletized PL. Means with the same letter are not significantly different at the *P* < 0.05 level.

Leachate Water Quality from Pasture Soil after Long-term Broiler Litter Applications

R.L. McMullen and K.R. Brye

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Resource demands are intensified when concentrated broiler production occurs in small geographic regions. Producers in such regions take advantage of the nutrients contained in waste products like broiler litter (BL) to enhance yields of forage grasses. Unfortunately, application of BL to pasture soils in karst regions can potentially reduce groundwater quality due to leaching of nutrients and metals. Previous studies examining nutrient losses from BL-amended soil tend to focus on nitrate (NO_3-N) and phosphate (PO_4-P) losses, are generally short-term in duration, and use older technologies for sampling. The objective of this study was to evaluate BL application rate effects on leachate concentrations and loads from soil using automated equilibrium tension lysimetry over an 8-year period. It was hypothesized that continued annual additions of BL would increase leachate concentrations and loads of BL-derived nutrients.

PROCEDURES

Site Description

Research was initiated in 2002 (Pirani, 2005) at the University of Arkansas System Division of Agriculture Agricultural Research and Extension Center in Fayetteville, Ark. Six plots, 19.7 feet long by 4.9 feet wide, were established on a Captina silt loam (fine-silty, siliceous, active, mesic Typic Fragiudult; Harper et al., 1969), with a 5% west-to-east slope (Pirani, 2005). All plots had a history of land-applied BL prior to 2002. Initially, ground cover was predominately tall fescue (*Lolium arundinaceum* Shreb.; Pirani, 2005), but in recent years other species have become increasingly common: clover (*Trifolium* spp.), Johnson-grass (*Sorghum halepense* (L.) Pers.) and Bermudagrass (*Cynodon dactylon* L.). During the study, forage was removed 4 times annually during the first week of May, June, July, and September to a height of 3.5 inches. Plots were initially chosen based on preliminary data suggesting plot similarities with regard to soil pH and high soil-test P in the top 2 in. (Table 1; Pirani, 2005; Pirani et al., 2006). Plots had previously been used in runoff studies and were equipped with steel edging to prevent surface water run-on and channeled runoff from within the plots to aluminum collection gutters positioned on the down-slope side of each plot.

Automated stainless steel equilibrium tension lysimeters (30 in. long by 10 in. wide; Brye et al., 1999) were installed under each plot in late summer 2002 (Pirani et al., 2006). The stainless steel, 0.2-µm, porous collection plates were positioned for a soil interface at a depth of 35 in. (Pirani et al., 2006). Soil matric potentials were automatically monitored every 10 min via heat dissipation sensors (229-L; Campbell Scientific, Logan, Utah) placed in the bulk soil at the 35-in. depth and just above the porous plate of the lysimeters. A vacuum pump (TD-2N; Brailsford and Company, Rye, N.Y.) was installed to remove leachate from the soil column in response to the natural fluctuations of the monitored soil matric potentials. The vacuum applied to remove leachate was equivalent to 2 kPa less than the measured matric potential in the bulk soil to avoid ponding above the porous plate. Additional information regarding lysimeter installation and datalogger programming was reported in Brye et al. (1999), Pirani (2005), Pirani et al. (2006), and Pirani et al. (2007).

Experimental Design

Six field plots were arranged in a randomized complete block design with two replications to evaluate BL application rate effects on annual drainage, soil leachate chemistry, and elemental leaching losses. Three litter application rates were imposed. A control treatment received no annual BL. A low and high BL rate treatment, 2.5 and 5.0 ton dry litter/acre, respectively, were established based on the current University of Arkansas System Cooperative Extension Service's litter application recommendations when the study began in 2002 (Pirani et al., 2006), but have since changed (UADACES, 2006). Three BL samples were collected each year and characterized using procedures for manure analysis. Litter pH and electrical conductivity (EC) were determined using a 1:2 BL:water mixture. Litter was digested in HNO_3, treated with H_2O_2, and analyzed with inductively coupled plasma mass spectrometry (ICP; CIROS CCD model, Spectro Analytical Instruments, Mass.).

Leachate Collection and Processing

Leachate was collected from lysimeters using a vacuum pump approximately every two weeks during dry periods or more frequently as needed. The volume of leachate, pH, EC, and oxidation-reduction potential (Redox) were measured after collection. Samples were filtered using a 1.6-µm glass microfiber filter. Once filtered, three 20-mL aliquots were acidified and three aliquots were left unacidified. Samples were then stored at 39 °F (4 °C) until analyses.

Total dissolved As, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Se and Zn concentrations were determined by ICP on acidified aliquots. Total dissolved organic carbon (DOC) was determined using a Shimadzu Total Organic Carbon Analyzer (Model TOC-CSH, Shimadzu Scientific Instruments, Columbia, Md.) on unacidified aliquots. Ammonium-N (NH_4-N, acidified aliquots), PO_4-P (acidified aliquots) and NO_3-N (unacidified aliquots) concentrations were determined using a Skalar San Plus automated wet chemistry analyzer (Skalar Analytical B.V., The Netherlands).

Soil Processing

Prior to initiation of the study and again at the end of the seventh year, four composite soil samples (0- to 4- in.) were collected in each plot and combined. Soil pH was determined using a 1:2 soil:water mixture and Mehlich-3 extractable nutrients (P, K, Ca, Mg, S, Na, Fe, Mn, Zn, and Cu) were determined using ICP.

Calculations

Leachate flow-weighted mean (FWM) concentrations (mg/L) and mass losses per unit area (i.e., loads, lb/acre) were determined annually for each dissolved ion. A year was designated as starting when BL was applied in May one year and ending when BL was re-applied in May of the following calendar year. Flow-weighted mean concentrations were calculated by dividing the total elemental mass lost during the year of interest for each plot by the total drainage. Loads were calculated by dividing the total elemental mass lost for a given plot during the year by the lysimeter collection area (2.1/sq ft). Similarly, annual mean pH, EC, and redox were calculated for each plot.

Analysis of covariance was used to identify BL effects on annual mean drainage, pH, EC, redox, and annual leachate FWM concentrations and loads of NO_3-N, NH_4-N, PO_4-P, As, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Na, Ni, P, Se, and Zn through the 8-year period using SAS (version 9.2; SAS Institute Inc., Cary, N.C.; PROC MIXED). Means were separated using contrast statements.

RESULTS AND DISCUSSION

Broiler litter composition was consistent from year to year for most elements/ions. However, the more volatile compounds such as NO_3-N and NH_4-N and the metals tended to have larger ranges indicating greater variability (Table 1).

Soil pH and Mehlich-3-extractable soil P, Mg, Mn, Zn, and Cu increased with additions of BL over time in the top 4 in. (Table 2). Similarly, extractable soil Ca, S, and Fe also increased, but only in the high litter rate. Mehlich-3-extractable soil Na did not change over time. Extractable soil K decreased in control plots.

Many leachate parameters were unaffected by BL or time. In these cases, the overall annual mean for the 8-year period is shown in Table 3. Adams et al. (1994) reported NO_3-N moved through a Captina soil in a series of peaks in response to BL amendments. The first peak occurred at a depth of 24 in., 30 days after BL application with a concentration >10 mg NO_3-N/L. Plots receiving 4.5 ton BL/acre later peaked again at a depth of 48 in., 120 days after application. Between multiple peaks, leachate concentrations returned to baseline. Results reported in this study are similar to results reported by Adams et al. (1994) when soil was amended with 4.5 ton BL/acre. In both cases leachate NO_3-N concentration did not exceed drinking water standards.

The flow-weighted mean Na concentration was the only monitored parameter to be affected by BL application rate and time (Table 4). Additions of BL increased the leachate FWM Na concentration over time while the control remained unchanged (Fig. 1).

Figure 2 shows that the rate of Ni loss over time was similar for all treatments at 0.015 lb Ni/acre/yr, but y-intercepts differed by BL treatment. The high BL treatment y-intercept was 0.12 lb Ni/acre and differed from the low BL treatment (0.07 lb Ni/acre). The control y-intercept was 0.01 lb Ni/acre and did not differ from soil receiving either BL rate (Fig. 2).

Leachate FWM P concentration did not change over time (Table 4); however, the control treatment had a greater concentration (0.24 mg P/L) than did the low (0.12 mg P/L) and high (0.12 mg P/L) treatments, which were similar to one another. Other leaching studies have reported minimal P loss in soil leachate (Brock et al., 2007; Sinaj et al., 2002). Jensen et al. (1998) reported that most of the ^{32}P added to soil was retained in the upper few millimeters of soil. At soil depths greater than 6 in., ^{32}P was detected at background levels. In addition, Brock et al. (2007) suggested that subsoil P saturation may increase P losses in soil leachate.

The remaining leachate properties were only influenced by time (Table 4). Redox, FWM concentrations of NH_4-N, As, Fe, Mn, and Ni and loads of NH_4-N, As, Fe, and Mn decreased over time, while FWM concentrations of Ca, Cu, Mg, and Se and loads of Cu and Se increased over time.

PRACTICAL APPLICATIONS

Annual soil leachate concentrations and loads of NO_3-N and PO_4-P were unaffected by BL application rate indicating that the soil is effectively filtering these compounds as water moves downward. In contrast, leachate Cu and Se loads increased over time suggesting that these metals are accumulating in the soil. In the future, if soil pH was to change, it is possible that a flush of soluble metals could leave the profile at concentrations in excess of drinking water standards.

Soil drainage did not vary by year, yet a decreasing leachate redox suggests oxygen levels are decreasing with time within the soil profile. This may be related to any number of factors including: increased soil water residency time, decreased water demand associated with shifts in forage speciation, or increased microbial activity.

With the exception of K and Na, Mehlich-3-extractable soil nutrients increased over time when soil was amended with BL indicating an accumulation of bioavailable nutrients. Mehlich-3-extractable soil K decreased when BL was withheld for 7-years indicating a decline in soil K availability. This may be related to K removal via forage harvesting.

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Table 1. Mean annual broiler litter composition and elemental addition rate in the low- (2.5 ton/acre) and high- (5.0 ton/acre) litter treatments over an 8-year study period. Annual mean minima and maxima are provided as an indication of parameter range. Litter was hand-applied once annually approximately the first week of May each year of the study.

Litter property	Mean annual composition	8-year Minimum	8-year Maximum	Mean annual litter rate Low	High
				---------- (lb/acre) -----------	
Moisture (kg/kg)	0.24	0.21	0.27		
pH	8.4	8.0	8.8		
EC* (dS/m)	11.9	9.8	14.8		
NO_3-N (mg/kg)	207	38	513	1.0	2.1
NH_4-N (mg/kg)	4640	2877	7183	23.2	46.4
Total elements					
C (%)	37.1	33.9	39.5	1856	3710
N (%)	4.4	4	5.3	220	440
P (%)	2.2	1.6	2.6	110	220
K (%)	3.5	2.9	4.4	175	350
Ca (%)	3.7	2.9	4.4	185	370
Mg (%)	0.7	0.6	0.8	35.0	70.0
S (%)	1.1	0.6	1.6	55.0	110.0
Na (mg/kg)	9098	3857	16094	45.5	91.0
Al (mg/kg)	347	243	558	1.7	3.5
Fe (mg/kg)	413	197	613	2.1	4.1
Mn (mg/kg)	568	421	751	2.9	5.7
Zn (mg/kg)	510	395	645	2.6	5.1
Cu (mg/kg)	496	298	678	2.5	5.0
B (mg/kg)	52.6	46.5	60.9	0.26	0.53
Ni (mg/kg)	10.4	5.9	16.1	0.052	0.104
Cd (mg/kg)	0.19	0.05	0.60	0.001	0.002
Cr (mg/kg)	7.7	3.1	15.6	0.04	0.08
As (mg/kg)	26.8	19	39.9	0.13	0.27
Se (mg/kg)	3.5	1.6	7.3	0.017	0.035

* EC, electrical conductivity.

Table 2. Select soil chemical properties before (2003) and after 7 years (2010) of broiler litter (BL) treatments. Litter was hand-applied once annually at 0 (Control), 2.5 (Low), and 5.0 ton/acre (High). Study years were defined as starting the first week of May when BL was applied and ending the following year when BL was reapplied.

Soil chemical property	2003 Control	2003 Low	2003 High	2010 Control	2010 Low	2010 High
pH*	6.31 b†	6.29 b	6.20 b	6.42 ab	6.67 a	6.70 a
Extractable Element (ppm)‡						
P	187 c	181 c	209 bc	152 c	262 b	404 a
K	188 ab	192 ab	200 a	83 c	158 b	182 ab
Ca	1177 abc	1134 bc	1052 c	1304 abc	1612 ab	1625 a
Mg	122 bc	110 c	111 c	96 c	171 ab	195 a
S	12.5 ab	13.6 ab	13.0 ab	11.4 b	14.7 ab	15.2 a
Na	11.9 a	12.7 a	12.1 a	6.0 a	13.0 a	13.0 a
Fe	176 b	165 b	175 b	227 ab	218 ab	251 a
Mn	148 bc	154 bc	137 c	218 ab	228 a	209 abc
Zn	13.3 b	13.9 b	12.3 b	11.9 b	24.0 a	26.4 a
Cu	4.9 b	4.3 b	4.3 b	3.8 b	10.0 ab	14.6 a

* pH determined using 1:2 soil:water mixture.
† Means in the same row with different letters are different as determined by Tukey's HSD ($\alpha = 0.05$).
‡ Mehlich-3 extractable elements were determined using ICP.

Table 3. Select soil leachate property means for parameters that were unaffected by broiler litter or time.

Leachate property	Mean
Drainage (in.)	18.55
pH	6.17
EC* (μS/cm)	190.3
Concentrations (mg/L)	
NO_3-N	0.11
PO_4-P	0.13
DOC†	3.69
Cr	0.01
K	18.2
Zn	0.28
Loads (lb/acre)	
NO_3-N	0.42
PO_4-P	0.43
DOC	13.8
Ca	70.4
Cd	< 0.01
Cr	0.03
K	80.7
Mg	24.4
Na	55.6
P	0.49
Zn	0.91

* EC, electrical conductivity.
† DOC, dissolved organic carbon.

Table 4. Analysis of covariance summarizing the effects of broiler litter (BL), time (Year), and their interaction on select soil leachate properties.

	Source of variance		
Leachate Property	BL*	Year†	BL × Year‡
	----------(*P*-value)----------		
Redox	0.6104	< 0.0001	0.8374
Concentrations (mg/L)			
NH_4-N	0.6993	0.0495	0.8767
As	0.8559	0.0003	0.9943
Ca	0.1200	0.0036	0.3525
Cu	0.3239	< 0.0001	0.2046
Fe	0.0685	< 0.0001	0.1422
Mg	0.2290	0.0156	0.3353
Mn	0.7711	0.0368	0.1452
Na	0.0012	0.0021	0.0012
Ni	0.8957	0.0059	0.7992
P	0.0089	0.2698	0.7842
Se	0.8981	< 0.0001	0.7961
Loads (lb/acre)			
NH_4-N	0.4314	0.0159	0.7280
As	0.7310	0.0010	0.7501
Cu	0.1029	< 0.0001	0.2900
Fe	0.5732	0.0004	0.9297
Mn	0.5329	0.0113	0.6409
Ni	0.0495	0.0056	0.4899
Se	0.4114	< 0.0001	0.5091

* Test for differences among y-intercepts for BL rates.
† Test if slope is different than zero.
‡ Test for differences among slopes due to BL rate.

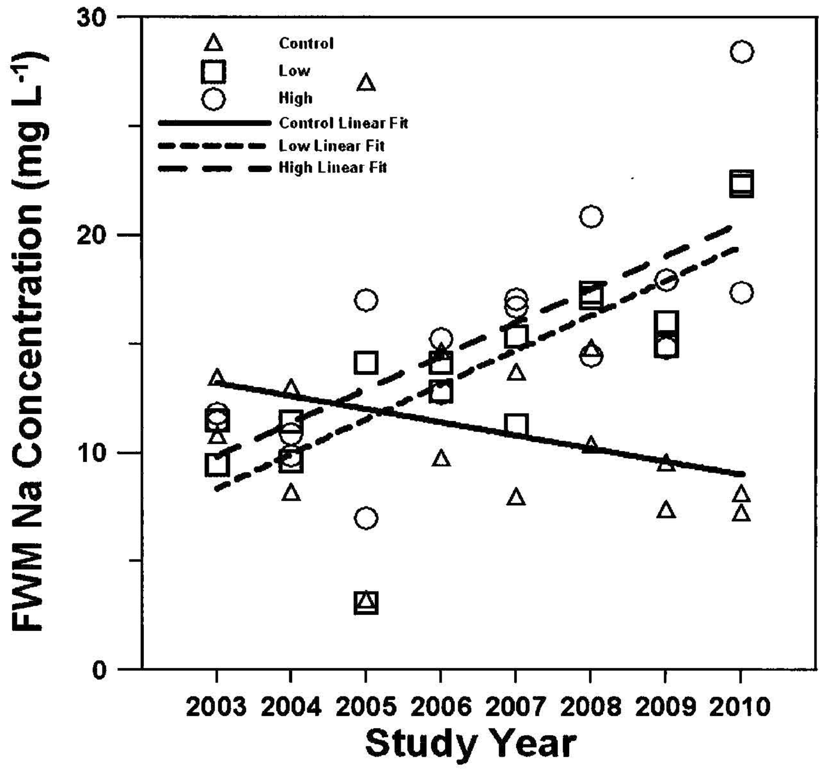

Fig. 1. Leachate flow-weighted mean sodium (FWM Na) concentration trends over an 8-year period. Pasture soil was amended once annually with broiler litter (BL) at three application rates (0, 2.5, and 5.0 ton BL/acre; control, low, and high, respectively). Study years were defined as starting the first week of May one year when BL was applied and ending the following year when BL was reapplied.

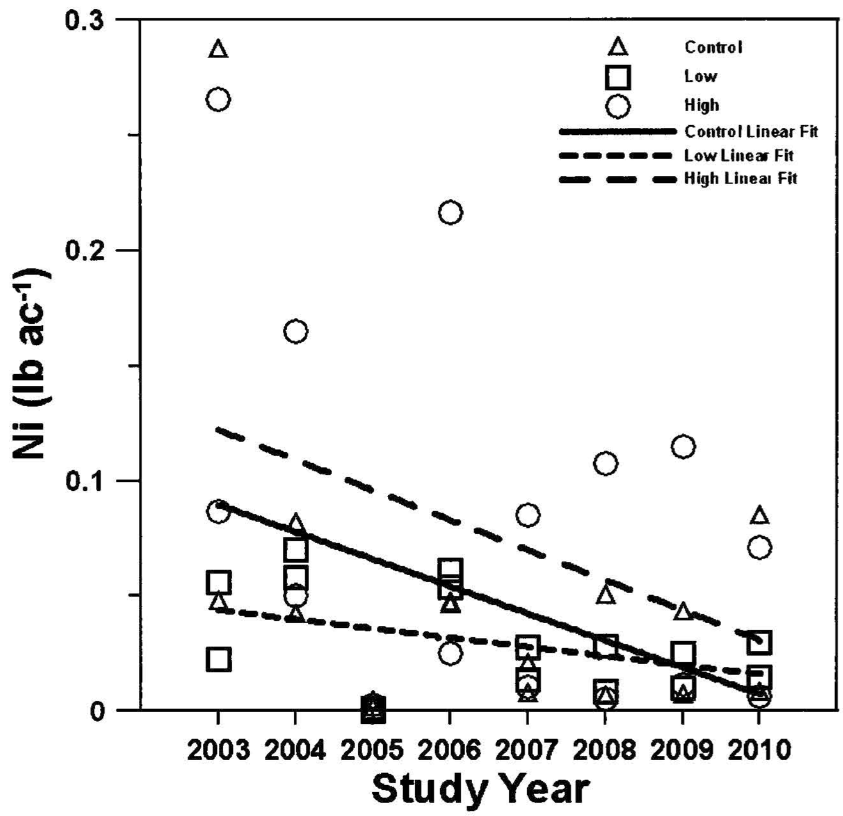

Fig. 2. Leachate nickel (Ni) load trends over an 8-year period. Pasture soil was amended once annually with broiler litter (BL) at three application rates (0, 2.5, and 5.0 ton BL/acre; control, low, and high, respectively). Study years were defined as starting the first week of May one year when BL was applied and ending the following year when BL was reapplied.

Soil Applied Phosphorus and Potassium Increase Corn Yield in Arkansas

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Favorable market prices have increased corn (*Zea mays* L.) production in Arkansas. In 2011, approximately 520,000 acres of corn were harvested in Arkansas. A corn grain yield of 175-bu/acre removes the equivalent of 60 lb phosphorus (P_2O_5) and 45 lb potassium (K_2O)/acre in the harvested grain (International Plant Nutrition Institute, 2012). Thus, P and/or K deficiency will limit corn yield, in many agricultural soils, if the nutrients removed by the harvested grain are not replenished by fertilization. In recent years, P and N transport from agricultural soils have been implicated as factors contributing to the hypoxic zone in the Gulf of Mexico. Applying the right rate of P and K will enable the growers to maximize the net returns from corn production and protect the environment. Reliable soil-test based fertility recommendations are the key to applying the right rate of P or K. Unfortunately, very little information is available describing corn response to P or K fertilization under current Arkansas production practices and the limited data that is available is based on a modified (1:7) Mehlich-3 test which is no longer in use. In 2010, we initiated replicated field experiments to evaluate corn response to P and K fertilization. The reliability and applicability of such information will increase if the studies are conducted on an array of soils with a range of Mehlich-3 extractable P and K concentrations. The specific research objectives were to evaluate the effect of soil-applied P or K fertilizer rates on corn ear-leaf P or K concentration at silking and grain yield.

PROCEDURES

Phosphorus Experiments

Six replicated P fertilization trials were conducted in 2012 including sites at the Lon Mann Cotton Research Station in Lee County (LEZ26), University of Arkansas Rohwer Research Station in Desha County (DEZ21) and four commercial fields in Arkansas (ARZ21), Clay (CLZ21), Cross (CRZ21), and Green counties (GRZ21) on soils typically used for corn production in Arkansas. Prior to P application, soil samples were taken from the 0- to 6-in. depth and composited by replication at all sites except LEZ26 where soil samples were collected from each 0 lb P_2O_5/acre plot of a P fertilization trial established in 2011. Soil samples were dried, crushed, extracted with Mehlich-3 solution, and the concentrations of elements in the extracts were measured by inductively coupled plasma atomic emission spectroscopy. Soil pH was measured in a 1:2 (weight: volume) soil-water mixture and particle size analysis was performed by the hydrometer method (Arshad et al., 1996).

Selected agronomically important information is listed in Table 1. The previous crop was soybean [*Glycine max* (L.) Merr.] at ARZ21, CLZ21, and CRZ21; grain sorghum [*Sorghum bicolor* (L.) Moench] at DEZ21; and corn at GRZ21 and LEZ26. Phosphorus application rates ranged from 0 to 160 lb P_2O_5/acre in 40 lb P_2O_5/acre increments as triple superphosphate. The experimental design was a randomized complete block where each treatment was replicated six times. Phosphorus treatments were applied onto the soil surface in a single application either before pulling the beds for planting (CRZ21, GRZ21) or after crop emergence (ARZ21, ClZ21, DEZ21 and LEZ26). Blanket applications of muriate of potash and $ZnSO_4$ supplied 60 to 90 lb K_2O, ~5 lb S, and ~10 lb Zn/acre, respectively. All experiments were fertilized with a total of 280 to 310 lb N/acre as urea or urea ammonium nitrate (32% N) in two or three split applications (e.g., preplant, 3- to 6-leaf stage and/or pre-tassel) depending on the location. Corn was grown on beds and furrow irrigated as needed by the cooperating grower or research station staff. Each plot was 25-ft long and 10-to 12.6-ft wide allowing for four rows of corn spaced 30 or 38 in. apart, depending on the location. Corn management closely followed University of Arkansas Cooperative Extension Service recommendations for irrigated corn. Soil chemical property means are listed in Table 2.

When corn was at the early- to mid-silk stage, ear-leaf samples were collected from 10 plants/plot at four of the sites. Leaf samples were dried in an oven at 70 °C to a constant weight, ground to pass through a 60-mesh sieve and P concentration was measured following wet digestion (Jones and Case, 1990). The middle two rows of each plot were harvested either with a plot combine or by hand with harvested ears placed through a combine later. The calculated grain yields were adjusted to a uniform moisture content of 15.5% before statistical analysis.

Potassium Experiments

Replicated field experiments were conducted at five sites including the Rohwer Research Station in Desha County (DEZ22) and commercial production fields in Arkansas (ARZ24), Clay (CLZ22), Cross (CRZ22), and Prairie (PRZ22) counties. The previous crop was corn at DEZ22 and soybean at all other locations. Potassium tests were adjacent to the P rate studies at all sites except DEZ22. The agronomic information for K trials is described in Table 1 and was similar to the P studies. Prior to K application, soil samples were taken from the 0- to 6-in. depth, processed as described previously, and are summarized in Table 3.

Potassium application rates ranged from 0 to 200 lb K_2O/acre in 40 lb K_2O/acre increments and K was applied as muriate of potash using the same procedures outlined for the P experiments. Triple superphosphate and $ZnSO_4$ were broadcast to supply 40 to 80 lb P_2O_5, ~10 lb Zn, and ~5 lb S/acre. At DEZ22, the plots were 40-ft long and 12.6-ft wide allowing for four rows of corn planted in 38-in. wide rows. At the other four locations plots were 25-ft long and either 10- or 12.6-ft wide allowing for four rows of corn planted in 38- or 30-in. wide rows. All experiments were randomized complete block designs and each treatment was replicated six times.

Analysis of variance was performed for P and K tests using the GLM procedure of SAS (SAS Institute, Inc., Cary, N.C.). Each experiment was analyzed separately. When appropriate, significant differences among means were separated by the least significant difference (LSD) test with significance interpreted at the 0.10 level. If corn responded positively to a nutrient application, we investigated the relationship between the nutrient application rate and grain yield or compared the mean of the no P or K control to the mean of a rate close to the recommended rate, or other rates of that nutrient using orthogonal contrasts.

RESULTS AND DISCUSSION

Phosphorus Experiments

The soil texture was determined to be a silt loam at five sites (22 % to 25% clay) and a silty clay (51% clay) at DEZ21 (Table 2). Mehlich-3 extractable P ranged from 14 to 82 ppm. According to the current University of Arkansas interpretation, the soil-test P level was Above Optimum (>50 ppm) at DEZ21, Optimum (36 to 50 ppm) at CRZ21, Medium (26 to 35 ppm) at CLZ21, Low (16-25 ppm) at ARZ21 and LEZ26 and Very Low (<16 ppm) at (GRZ21) and would receive recommendations for 0, 0, 75, 100, and 120 lb P_2O_5/acre, respectively.

Phosphorus fertilization significantly ($P \leq 0.10$) affected corn ear-leaf P concentration at CRZ21 and GRZ21 (Table 4). Although not significant, ear-leaf P increased numerically as P rate increased at ARZ21 and CLZ21. These results are consistent with our 2011 studies (Mozaffari and Slaton, 2012) and suggest that ear-leaf P concentration is a good indicator of soil P availability. Ear-leaf P concentrations in corn that did not receive any P fertilizer ranged from 0.20% to 0.32% P compared to 0.25% to 0.35% P for corn treated with 160 lb P_2O_5/acre. The established critical corn ear-leaf P concentration is 0.25% (Campbell and Plank, 2000). For sites where ear-leaf tissue was collected, the ear-leaf P concentrations were lowest at GRZ21 and greatest at CRZ21, which also had the lowest and highest soil-test P values among sampled sites, respectively.

Corn grain yields were significantly increased (Table 4) by P fertilization at ARZ21, GRZ21, and LEZ26, the three sites with Low to Very Low soil-test P (Table 2). Orthogonal contrasts indicated a significant ($P \leq 0.0484$) linear grain yield response to P application rate at these sites (Table 4). At GRZ21 and LEZ26, the grain yield of corn fertilized with ≥80 lb P_2O_5/acre was significantly higher than corn that received no P. Phosphorus fertilization did not influence corn grain yields at CLZ21, CRZ21, and DEZ21. Lack of response to P fertilization at these sites, which had Medium or Above Optimum soil-test P levels, is consistent with the current University of Arkansas Cooperative Extension Service corn fertilization recommendations and interpretations. For these six corn trial sites, Mehlich-3 soil-test P was a reliable tool for identifying soils that would positively respond to P fertilization.

Potassium Experiments

The soil texture was silt loam at all five sites except PRZ22, which was a silty clay loam (Table 3). The average Mehlich-3 extractable K ranged from 64 to 114 ppm among site-years. According to the University of Arkansas soil test interpretation, the soil-test K was 'Low' (61 to 90 ppm) at DEZ22 and CLZ22 and 'Medium' (91 to 130 ppm) at the other three sites. Current fertilization guidelines recommended 110 and 75 lb K_2O/acre for 'Low' and 'Medium' soil-test K levels, respectively.

Potassium fertilization significantly ($P \leq 0.10$) increased corn ear-leaf K concentration at all sites, but ARZ24 (Table 5). Ear-leaf K concentration ranged from 1.20% to 1.65% K for corn that received no K and 1.60% to 2.09% K for corn fertilized with 200 lb K_2O/acre. The mean ear-leaf K concentrations in corn that received no K fertilizer were the lowest at DEZ21 and CLZ21, which had the lowest soil-test K values (Table 3). Corn ear leaf concentrations <1.80% K indicate possible K deficiency (Campbell and Plank, 2000). Based on this suggested critical K concentration, positive yield increases from K fertilization would have been expected at all sites. Application of 80 lb K_2O/acre increased the ear-leaf K concentrations to the sufficiency level at CLZ22 and CRZ22, but 200 lb K_2O/acre was needed to raise the ear-leaf K to 1.80% at DEZ21 (Table 5).

Potassium fertilization significantly ($P \leq 0.10$) affected corn grain yields at DEZ22, CRZ22, and PRZ22, but, did not influence corn grain yield at ARZ24 and CLZ22 (Table 5). Grain yield responses to K fertilization, at the responsive sites, were not consistent among K fertilizer rates. There was a significant linear relationship between K application rate and corn grain yield at DEZ22 ($P < 0.10$), but not at CRZ22 or PRZ22 ($P >$ 0.18). The mean yield of the corn receiving 0 lb K_2O/acre was significantly ($P < 0.10$) different than the grain yield of corn fertilized with ≥ 80 lb K_2O/acre at DEZ22, and the mean yield of corn fertilized with 120 and 160 lb K_2O/acre at CRZ22. The different corn yield responses to K fertilization at the three sites with a Medium soil K level (ARZ24, CRZ22, and PRZ22) warrants additional investigation. The positive grain yield response to K fertilization at DEZ22 (Low soil-test K) and the lack of a yield increase to K fertilization at ARZ24, CLZ22, and PRZ22 (Medium soil-test K) are consistent with the current University of Arkansas interpretation of Mehlich-3 extractable K for corn production.

PRACTICAL APPLICATIONS

The 2012 results show that P fertilization significantly and linearly increased corn grain yield, when prefertilization Mehlich-3 extractable P in the 0- to 6-in. depth was Low or Very Low. Corn did not respond positively to P fertilization when soil-test P was Medium or higher. These results are similar to our 2010 and 2011 results where corn did not respond to P fertilization when Mehlich-3 extractable P was 'Medium' or above (≥ 26 ppm) (Mozaffari and Slaton, 2011, 2012). In the K fertilization trials, K fertilization significantly increased corn grain yield at two sites that had either a Low or Medium soil-test K level. Potassium fertilization did not influence corn yield at one site with a Low soil-test K level and two sites with Medium soil-test K. Additional tests on soils with a wide array of soil-test K values are needed to ascertain whether our interpretation of soil-test K needs to be changed.

In general, our 2012 and previous years' results suggest that current University of Arkansas soil-test-based P and K fertilizer recommendations are able to identify soils that need no P. Potassium recommendations for corn need further evaluation, as there appears to be some variability in the measured responses. Given the diversity of our soils, additional research on soils with a range of soil-test P and K is needed to evaluate the reproducibility of these results.

ACKNOWLEDGMENTS

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Table 1. Soil series, corn hybrid, planting, fertilizer application, leaf sampling and harvest dates for P and K fertilization trials conducted in Arkansas (ARZ21, ARZ24), Clay (CLZ21, CLZ22), Cross (CRZ21, CRZ22), Desha (DEZ21, DEZ22), Lee (LEZ26), and Prairie (PRZ22) counties during 2012.

Site	Test nutrient	Soil series	Hybrid	Planting date	Fertilizer application date	Ear-leaf sampling date	Harvest date
ARZ21	P	Dewitt silt loam	Pioneer 1615HR	26 March	4 April	18 June	29 July
ARZ24	K	Dewitt silt loam	Pioneer 1656HR	7 April	13 April	18 June	8 Aug
CLZ21 &22	P, K	Calloway silt loam	DeKalb DKC66-97	30 March	6 April	16 June	15 Aug
CRZ21 &22	P, K	Arkabutla silt loam	Progeny 27V01	5 April	3 April	19 June	16 Aug
DEZ21	P	Sharkey & Desha clay	Pioneer 1184HR	9 April	12 April	NC[a]	24 Aug
DEZ22	K	Hebert silt loam	Pioneer 1184HR	10 April	12 April	20 June	24 Aug
GRZ21	P	Calloway silt loam	DeKalb DKC66-96	6 April	6 April	25 June	3 Aug
LEZ26	P	Calloway silt loam	Pioneer 1184HR	12 April	14 May	NC	28 Aug
PRZ22	K	Stuttgart silt loam	DeKalb DKC64-69	28 March	2 April	22 June	31 July

[a] NC, ear-leaf samples not collected.

Table 2. Selected mean properties of soil samples collected from the 0- to 6-in. depth, before P-fertilizer application, for six P fertilization trials established in Arkansas (ARZ21), Clay (CLZ21), Cross (CRZ21), Desha (DEZ21), Green (GRZ21), and Lee (LEZ26) counties during 2012.

			Mehlich-3-extractable nutrients						Soil physical properties			
Site ID	Soil pH[a]	P[b]	K	Ca	Mg	Mn	Cu	Zn	Sand	Silt	Clay	Texture
		(ppm)							(%)			
ARZ21	7.2	22	87	1159	155	192	1.0	3.6	12	66	22	silt loam
CLZ21	6.3	33	93	925	235	236	1.8	1.9	6	71	23	silt loam
CRZ21	6.9	37	113	1204	205	241	1.9	2.3	7	76	22	silt loam
DEZ21	7.4	82	246	2685	548	115	1.9	3.0	6	43	51	silty clay
GRZ21	5.7	14	92	769	118	254	1.4	4.8	4	73	23	silt loam
LEZ26	6.1	23	75	755	182	179	1.2	7.4	2	73	25	silt loam

[a] Soil pH was measured in a 1:2 (weight: volume) soil-water mixture.
[b] Standard deviation of soil-test P means: 2 ppm for ARZ21, 5 ppm for CLZ21, 3 ppm for CRZ21, 3 ppm for DEZ21, 1 ppm for GRZ21, and 7 ppm for LEZ26.

Table 3. Means for selected properties of soil samples taken from the 0- to 6-in. depths (by replication), before K-fertilizer application for five K fertilization trials conducted in Arkansas (ARZ24), Clay (CLZ22), Cross (CRZ22), Desha (DEZ22), and Prairie (PRZ22) counties during 2012.

Site ID	Soil pH[a]	P[b]	K	Ca	Mg	Mn	Cu	Zn	Sand	Silt	Clay	Texture
		Mehlich-3-extractable nutrients							Soil physical properties			
		(ppm)							(%)			
ARZ24	7.8	77	94	2522	255	197	1.3	3.3	5	74	21	silt loam
CLZ22	6.2	22	89	960	287	227	1.5	1.6	8	65	27	silt loam
CRZ22	7.1	37	114	1243	203	268	1.9	2.7	4	74	22	silt loam
DEZ22	6.8	35	64	797	131	123	0.9	1.8	22	63	15	silt loam
PRZ22	6.2	15	114	1244	213	434	0.8	7.0	5	64	31	silty clay loam

[a] Soil pH was measured in a 1:2 (weight: volume) soil-water mixture.

[b] Standard deviation of soil-test K in the 0-to 6-inch depths: 21 ppm for ARZ24; 9 ppm for CLZ22; 10 ppm for CRZ22; 4 ppm for DEZ22; and 7 ppm for PRZ22.

Table 4. Effect of P fertilization rate on ear-leaf P concentration at the silking stage and corn grain yield for six P fertilization trials established in Arkansas (ARZ21), Clay (CLZ21), Cross (CRZ21), Desha (DEZ21), Green (GRZ21), and Lee (LEZ26) counties during 2012.

	Arkansas County		Clay County		Cross County		Desha County		Greene County		Lee County	
P_2O_5 rate	Ear-leaf P	Grain yield	Ear-leaf P	Grain yield	Ear-leaf P	Grain yield	Ear-leaf P	Grain yield	Ear-leaf P	Grain yield	Ear-leaf P	Grain yield
(lb P_2O_5/acre)	(%P)	(bu/acre)	(%P)	(bu/acre)	(%P)	(bu/acre)	(%P)	(bu/acre)	(%P)	(bu/acre)	(%P)	(bu/acre)
0	0.32	185	0.26	230	0.33	234	ND[a]	198	0.20	177	ND	179
40	0.32	202	0.29	241	0.30	250	ND	197	0.22	196	ND	182
80	0.33	183	0.27	239	0.33	231	ND	203	0.24	213	ND	202
120	0.33	210	0.31	234	0.34	244	ND	197	0.25	220	ND	196
160	0.35	194	0.31	235	0.34	230	ND	203	0.25	221	ND	219
CV[b]5.7	7.9	17.5	14.9	6.9	9.6	-	7.7	7.6	11.4	-	12.3	
P value	0.1099	0.0317	0.3612	0.9857	0.0485	0.4852	-	0.8927	0.0008	0.0251	-	0.0416
LSD 0.10[c]	NS[d]	16	NS	NS	0.02	NS	-	NS	0.02	25	-	25

[a] ND = no data; ear-leaf samples were not collected at this research site.

[b] CV = coefficient of variation.

[c] LSD = Least significant difference at $P = 0.10$.

[d] NS = not significant ($P > 0.10$).

Table 5. Effect of K fertilization rate on corn ear-leaf K concentration, at the silk stage, and grain yield for five K fertilization trials conducted in Arkansas (ARZ24), Clay (CLZ22), Cross (CRZ22), Desha (DEZ22), and Prairie (PRZ22) counties during 2012.

	Arkansas County		Clay County		Cross County		Desha County		Prairie County	
K rate	Ear-leaf K	Grain yield	Ear-leaf K	Grain yield	Ear-leaf K	Grain yield	Ear-leaf K	Grain yield	Ear-leaf K	Grain yield
(lb K_2O/acre)	(%K)	(bu/acre)	(%K)	(bu/acre)	(%K)	(bu/acre)	(%K)	(bu/acre)	(%K)	(bu/acre)
0	1.65	201	1.46	210	1.76	219	1.20	191	1.49	214
40	1.74	212	1.61	229	1.72	223	1.25	192	1.58	220
80	1.57	204	1.81	201	1.91	215	1.39	202	1.55	211
120	1.70	206	1.85	216	2.10	245	1.65	205	1.56	205
160	1.75	197	1.91	209	1.97	238	1.65	210	1.66	203
200	1.67	196	2.00	217	2.09	225	1.82	208	1.60	215
CV[a]7.2	8.9	9.0	14.6	8.7	7.0	11.7	4.2	4.3	5.2	
P value	0.2725	0.9227	<0.0001	0.7703	0.0016	0.0348	<0.0001	0.0023	0.0087	0.0934
LSD 0.10[b]	NS[c]	NS	0.16	NS	0.12	17	0.17	8	0.07	11

[a] CV = coefficient of variation.
[b] LSD = Least significant difference at $P = 0.10$.
[c] NS = not significant ($P > 0.10$).

Cotton and Corn Respond Positively to Urea and an Enhanced Efficiency Fertilizer

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soil organic matter is an important source of potentially available N in many cropping systems. The organic matter content of many Arkansas agricultural soils is low (< 2.0%) requiring Arkansas growers to apply relatively high rates of N fertilizer to produce optimal cotton (*Gossypium hirsutumn* L.) and corn (*Zea mays* L.) yields. Soil and fertilizer N can be lost by processes such as runoff, leaching, and denitrification. Reducing N fertilizer loss to the environment will increase the growers' profit margins and reduce potential environmental risks associated with soil and fertilizer N. A polymer-coated urea (44% N, Agrium Advanced Technologies, Loveland, Colo.) is currently being produced in Missouri and marketed in Arkansas under the trade name of Environmentally Smart Nitrogen or ESN. According to the manufacturer, the polymer coating protects the urea-N against rapid loss to the environment with the N release rate controlled by temperature. The objective of this research was to evaluate cotton and corn yield response to ESN and urea in representative Arkansas soils.

PROCEDURES

Cotton Experiments

Two N-fertilization experiments were conducted in 2012 to evaluate cotton yield response to preplant application of urea, ESN, and combinations of urea and ESN. One experiment was located at the Lon Mann Cotton Research Station (LMCRS) in Marianna on a Calloway silt loam and the other trial was located at Northeast Research and Extension Center (NEREC) in Keiser on a Sharkey silty clay. Before applying any fertilizer, soil samples were collected from the 0- to 6-in. depth and composited by replication. Soil samples were oven dried, crushed, and soil pH and Mehlich-3 extractable nutrients were measured. Average soil properties in the 0- to 6-in. depth were 52 ppm P, 139 ppm K, 6.8 pH, 23% clay, and 25 ppm NO_3-N at the LMCRS and 60 ppm P, 237 ppm K, 6.7 pH, and 44% clay at the NEREC. Soil particle size analysis was performed by the hydrometer method (Arshad et al., 1996). Agronomically important information for all experiments is presented in Table 1.

Each cotton experiment was a randomized complete block design with a factorial arrangement of four urea-ESN combinations each applied at five rates ranging from 30 to 150 lb N/acre at 30 lb N/acre increments and a no N control. The four urea and ESN-N combinations were: 100% urea-N; 50% urea-N plus 50% ESN-N; 25% urea-N plus 75% ESN-N, and 100% ESN-N. Each treatment was replicated six times at LMCRS and five times at NEREC. We applied muriate of potash and triple superphosphate to supply 40 lb K_2O and P_2O_5/acre at both locations. All fertilizers (including the N fertilizer treatments) were hand applied onto the soil surface and incorporated immediately with a Do-all cultivator. We pulled the beds with a hipper and planted the cotton on top of the beds after fertilizers were incorporated. Each cotton plot was 40-ft long and 12.6-ft wide allowing for four rows of cotton planted in 38-in. wide rows. We furrow irrigated the cotton as needed and closely followed the University of Arkansas Cooperative Extension Service cultural recommendations for irrigated-cotton production. The two center rows of cotton in each plot were harvested with a spindle-type picker equipped with an electronic weight measuring and recording system.

Corn Experiment

A corn N-fertilization trial was conducted at the LMCRS on a Loring silt loam during 2012 growing season. The experimental treatments and design for the corn experiments were similar to the cotton experiments. The average soil chemical properties were 60 ppm P, 143 ppm K, 7.4 pH, and 8 ppm NO_3-N at the LMCRS corn trial. The N rates for the corn experiment ranged from 60 to 300 lb N/acre applied in 60 lb N/acre increments plus a no N control. Each treatment was replicated six times. Applications of muriate of potash, triple superphosphate, and $ZnSO_4$ were made to supply 60 lb K_2O, 40 lb P_2O_5, 10 lb Zn, and 5.0 lb S/acre. All fertilizers were hand applied onto the soil surface and incorporated immediately with a Do-all cultivator. The beds were pulled with a hipper and corn was planted on top of the beds after all fertilizers were incorporated. Corn was furrow irrigated as needed and the University of Arkansas Cooperative Extension Service recommended cultural practices were closely followed. Experimental plots were 25-ft long and 12.6-ft wide allowing for four rows of corn planted in 38-in. wide rows. Corn plants in the center 2-rows of each plot were harvested with a plot combine and grain yields were adjusted to 15.5% moisture content.

We obtained monthly precipitation data from weather stations at LMCRS and NEREC and long-term average precipitation data from the Arkansas Variety Testing Site (http://www.arkansasvarietytesting.com/crop/data/2). Analysis of variance (ANOVA) was performed using the GLM procedure of SAS (SAS Institute, Inc., Cary, N.C.). Data were analyzed by crop and site. The data from the control (0 lb N/acre) were not included in the ANOVA. When appropriate, means were separated by the least significant difference (LSD) method and interpreted as significant when $P \leq 0.10$.

RESULTS AND DISCUSSION

Monthly precipitation amounts from May through September of 2012 were consistently less than the long-term average (Table 2). Thus, the weather conditions were not conducive for significant N loss by leaching, runoff and/or denitrification, but N loss via these same pathways still could have occurred during irrigation events.

Cotton Experiments

Neither N source, nor the N source × N rate interaction significantly influenced seedcotton yield at either site ($P > 0.10$, Table 3). Seedcotton yields at both sites were significantly ($P < 0.0001$) affected by N-fertilizer rate. Averaged across the four urea and ESN blends, the seedcotton yield of cotton that received no N fertilizer averaged 2849 lb/acre at the LMCRS and 1278 lb/acre at the NEREC, highlighting the yield potential difference between the two locations. At each site, seedcotton yield increased numerically with increasing N application rate. Application of 150 lb N/acre produced the numerically highest seedcotton yields at both sites. The minimum N rate that produced the statistically greatest seedcotton yield at each site was 120 lb N/acre.

Corn Experiment

Nitrogen source, N rate, and their interaction significantly ($P < 0.0001$) influenced corn grain yield (Table 4). The grain yield of corn that did not receive any N fertilizer was 43 bu/acre. For each urea-ESN combination, yields increased with each incremental increase in N rate with maximal yields produced by application of 300 lb N/acre. For N rates ≥180 lb N/acre, grain yield often increased numerically and sometimes significantly as the proportion of ESN-N increased from 0 to 100%. For example, corn receiving 180 to 300 lb N/acre as urea (100%) produced significantly lower yields than corn fertilized with 25:75 (urea-ESN) or ESN (100%). We observed a comparable trend in 2010 (Mozaffari and Slaton, 2011).

PRACTICAL APPLICATION

The amount of precipitation in the 2012 growing season was well below normal, suggesting that any differences among preplant-applied treatments attributed to N loss via denitrification and leaching were most likely from crop irrigation. Nitrogen application rate significantly increased seedcotton yields and maximal yields were produced by 120 lb N/acre at both the LMCRS and NEREC. Averaged across N rates, seedcotton yields were not different among the various combinations of urea and ESN fertilizers at either site. At LMCRS, N application significantly increased corn grain yield and maximal yields were produced with 300 lb N/acre. Corn grain yields significantly increased with each incremental increase in N rate for all N sources and yields tended to increase as the percentage of ESN in the mixture increased. The grain yields of corn fertilized with 180 to 300 lb N/acre as either 25:75 ratio of urea:ESN or 100% ESN were 12% to 15% and 20% to 24%, respectively, greater than corn fertilized with the same rates of urea (100%). These results support our previous findings (Mozaffari and Slaton, 2011, 2012) and suggest that ESN is a viable N fertilizer that can be preplant incorporated for irrigated corn and cotton production in Arkansas. Additional research on a wide range of soils and weather conditions, particularly under higher than normal rainfall, is needed to gain a better understanding of the agronomic and environmental performance of ESN in Arkansas.

ACKNOWLEDGMENTS

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Table 1. Selected agronomically important information for cotton and corn N fertilization trials established at the Lon Mann Cotton Research Station (LMCRS) and Northeast Research and Extension Center (NEREC) during 2012.

Site ID	Previous crop	Soil series	Cultivar or hybrid	Planting date	N application date	Harvest date
LMCRS-cotton	cotton	Loring silt loam	Phytogen 375	4 May	3 May	4 Oct
NEREC-cotton	cotton	Sharkey silty clay	Stoneville 5458	18 May	15 May	29 Oct
LMCRS-corn	cotton	Calloway silt loam	Pioneer 1184HR	4 April	30 March	28 Aug

Table 2. Actual rainfall received by month in 2012 and the long-term (1960-2007) average monthly mean rainfall data at the Lon Mann Cotton Research Station (LMCRS) and Northeast Research and Extension Center (NEREC).

		Precipitation					
Site ID	Precipitation	May	June	July	August	September	Total
		(In.)					
LMCRS[a]	2012	1.50	0.78	2.55	1.21	4.86	11.0
LMCRS	Average[b]	5.90	3.90	3.90	2.80	3.20	19.7
NEREC[c]	2012	4.18[d]	2.52	2.38	1.15	6.98	17.2
NEREC	Average[b]	5.20	3.90	3.70	2.90	3.70	14.2

[a] At LMCRS, cotton and corn were planted on 4 May and 4 April, respectively. Cotton was harvested on 4 Oct and corn was harvested 28 Aug.
[b] Long-term average for 1960-2007.
[c] At NEREC, cotton was planted on 18 May and harvested on 29 Oct.
[d] 2.42 inches of the total rainfall in May occurred before planting cotton.

Table 3. Seedcotton yield as affected by the non-significant N source and N source × N rate interaction ($P > 0.10$) and significant ($P \leq 0.0779$) N rate (averaged across N sources) effect for two cotton N fertility experiments conducted at the Lon Mann Cotton Research Station and Northeast Research and Extension Center in 2012.

	N fertilizer combination (%)				
N rate	100% Urea-N	50%Urea-N 50%ESN-N[a]	25% Urea-N 75% ESN-N	100% ESN-N	N rate mean
(lb N/acre)	Seedcotton yield (lb/acre)				
Lon Mann Cotton Research Station					
0	2849[b]				
30	2786	3159	3215	3059	3042
60	2996	2820	3535	3139	3105
90	2969	3272	2958	3350	3122
120	3380	3467	3297	3154	3324
150	3249	3285	3224	3670	3357
LSD 0.10	NS[c]				214[d]
P-value	0.1843				0.0779
N rate					
(lb N/acre)	Seedcotton yield (lb/acre)				
Northeast Research and Extension Center					
0	1278[b]				
30	1922	2009	1701	1886	1878
60	2443	2045	2310	2068	2217
90	2467	2474	2211	2639	2448
120	2870	2595	2771	2779	2754
150	2956	3024	2745	2331	2764
LSD 0.10	NS[c]				183[d]
P-value	0.1047				<0.0001

[a] ESN = Environmentally Smart N, polymer coated urea.
[b] The no N control is listed for reference only as it was not included in the analysis of variance.
[c] NS = not significant ($P > 0.10$).
[d] LSD compares the yield of treatments that received N, averaged across N sources.

Table 4. Corn grain yield as affected by the significant (P = 0.0334) N source × N rate interaction for a corn N fertility experiment conducted at the Lon Mann Cotton Research Station in Marianna during 2012.

	N fertilizer combination			
	100% Urea-N	50%Urea-N 50%ESN-N[a]	25% Urea-N 75% ESN-N	100% ESN-N
(lb N/acre)	----Corn grain yield (bu/acre)----			
0	---- 43[b] ----			
60	91	82	94	86
120	127	143	135	142
180	156	171	175	194
240	178	201	204	214
300	194	219	223	237
LSD 0.10	----15----			
P-value	----0.0334----			

[a] ESN = Environmentally Smart N, polymer coated urea.
[b] The no N control is listed for reference only as it was not included in the analysis of variance.

Evaluation of Liquid Nitrogen Fertilizers UCAN 23 and UAN 32 at Varying Rates in Cotton

T.B. Raper, D.M. Oosterhuis, C. Pilon, and J.M. Burke

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Nitrogen recovery efficiency (NCE) by cotton (*Gossypium hirsutum*, L.) has been shown to vary from 12% to 30% in furrow-irrigated systems (Bronson, 2008; Constable and Rochester, 1988). Failure of a crop to recover and utilize the majority of the applied nitrogen (N) has far reaching financial and environmental implications. Fertilizer input costs have steadily risen with time; annual average fertilizer costs nearly tripled in the period from 2002 to 2012 alone (USDA-ERS, 2012). Environmental repercussions from over-application of N range from accumulation of nitrates in the subsoil to groundwater pollution (Boquet and Brietenbeck, 2000). Although less than optimal N rates reduce the amount of nitrates in the subsoil (McConnell et al., 1993), insufficient N can drastically reduce yields (Bondada and Oosterhuis, 2001; Wadleigh, 1944) and therefore result in poor stewardship through inefficient utilization of other applied inputs.

One of the most common fertilizers used on cotton in the Mississippi Delta is 32% UAN, which is a mixture of urea and ammonium nitrate. The N in this fertilizer is susceptible to volatilization, leaching, and denitrification. As a result, N fertilizer is recommended by the University of Arkansas Cooperative Extension Service to be applied in a split application to reduce N loss and increase NCE (Barber and McClelland, 2012). Another method which has been shown to increase NCE, and therefore increase yields at lower applied N rates, is the utilization of fertilizers which contain calcium (Ca; Ron and Loewy, 2007; Gately, 1994). Research has indicated that the addition of soluble Ca can increase ammonium uptake (Taylor et al., 1985) and reduce ammonia losses (Fenn et al., 1981; Witter and Kirchmann, 1989). Some studies have also shown synergistic effects when Ca and urea were used in combination (Horst et al., 1985). As a result of these studies and others, YaraLiva (Yara North America Inc, Tampa, Fla.) has developed a new liquid N fertilizer containing Ca. This product, UCAN-23, contains a total N concentration of 23% N, with 8% in the form of nitrate, 5% in the form of ammonium, and 10% in the form of urea. The fertilizer also contains 4% Ca. The main objective of this research was to examine the response of cotton to UCAN 23 in contrast to the commonly used UAN 32.

PROCEDURES

A randomized complete block trial consisting of five replications was designed and conducted at two locations in the 2012 growing season. The trial at the Lon Mann Cotton Research Center in Marianna, Ark., consisted of 4-row plots 50 ft in length. The trial at the Arkansas Agricultural Research and Extension Center in Fayetteville, Ark., consisted of 4-row plots 20 ft in length on 36-in. wide rows. Soil samples were taken in early February for the Marianna and the Fayetteville sites and sent to the Soil Testing and Research Laboratory at Marianna for analysis.

Stoneville 4288 B2RF cotton was planted at a seeding rate of 3.5 seeds/ft on 18 May and 14 May for the Fayetteville and Marianna sites, respectively. Treatments consisted of a 0 lb applied N/acre (control) and rates of 50, 75, and 100 lb N/acre from the N sources UCAN 23 and UAN 32. Fertilizer N applications were surface dribbled within 6 in. of the row and applied in split applications, with 12 lb N/acre applied after emergence and the remaining (38, 63, or 88 lb N/acre) split treatment applied during the second week of squaring. All other inputs were managed to assure that N was the only yield-limiting factor. After defoliation, 39.5 in. of row were hand-picked from the Marianna plots to determine boll number and ginned through a micro-gin to determine lint percentage. After hand-picking, a mechanical picker with a weigh cell harvested the center two rows of each four-row plot to determine seedcotton yield. At the Fayetteville site, 79 in. of row were hand harvested to determine boll number and after ginning with a micro-gin, lint weight and lint percentage were determined.

Statistical analysis tested fertilizer N rate (0, 50, 75, and 100 lb N/acre), N source (UCAN 23 and UAN 32), and the interaction between fertilizer N rate and source on the response variables of lint yield, boll number, and boll weight. Linear and quadratic yield and boll number responses for fertilizer N rate were tested and evaluated at a significance level of $P \leq 0.10$.

RESULTS AND DISCUSSION

Soil test reports from both sites indicated sufficient soil Ca concentrations (Table 1) and recommended an N rate for cotton of 90 lb N/acre. Visible differences between the check and treated plots were evident soon after the application of the second split application in Fayetteville. Unfortunately, the Fayetteville trial received severe hail damage within 2 weeks of the second application, from which the crop never fully recovered. Still, the response of lint yield and boll number to fertilizer N rate was significant at the $P \leq 0.10$ and $P \leq 0.05$ levels, respectively. Both significant response variables increased positively and linearly as fertilizer N rate increased (Fig. 1). Source of N did not significantly affect yield. The hail damage at the Fayetteville location prevented the establishment of strong N stress, as yield potential was destroyed.

Visible differences between the control and N-treated plots were also evident at the Marianna site soon after the second N (split) application was made, however a significant rainfall event did not occur to move the fertilizer down the profile from the top of the bed. As a result, the stained fertilizer band was visible on the bed late into the boll-fill stage. Still, the quadratic response of lint yield to fertilizer N rate was significant ($P \leq 0.10$) suggesting the optimal N rate was reached and exceeded by the 100 lb N/acre rate. The agronomically optimal fertilizer N rate appeared to be near 75 lb N/acre. As in the Fayetteville trial, boll number was also significantly increased by increased fertilizer N rate ($P \leq 0.05$), but average boll weight was not significantly affected (not shown). This is most likely due to the ability of the cotton plant to shed bolls which it cannot adequately fill. Failure of increased N fertilizer rate to significantly increase average boll weight has also been noted in prior studies (Bondada and Oosterhuis, 2001). Also, the source of fertilizer N did not have a significant impact on seedcotton yield at the Marianna site. Failure of N source to affect yield parameters may in part be due to high concentrations of Ca already present in the soil. According to the University of Arkansas Cooperative Extension Service, Ca deficiencies are not commonly observed in soils above 400 ppm or in soils where the pH is maintained in the recommended range (Espinoza et al., 2012).

PRACTICAL APPLICATIONS

Lint yield response to fertilizer N at the Marianna site supports results of previous research which suggest excessive N applications can negatively impact yield. Although significant differences were not noted between cotton receiving UAN 32 and UCAN 23 at either tested site, Ca concentrations and soil pH at both sites were within the sufficient range for optimal cotton production. More research must be conducted to determine if UCAN 23 has a positive effect on cotton yield in fields that possess insufficient soil Ca concentrations or low soil pH.

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Table 1. Soil-test results from samples taken from two trials in early February 2012. The results for the Marianna site represent the value of one composite soil sample. The results for the Fayetteville site represent the range from four composite samples.

	Mehlich-3-extractable soil calcium		
Location	Calcium content of soil	Estimated base saturation	pH (1:2 soil-water)
	(ppm Ca)	(% Ca)	
Marianna, Ark.	967	52.1	7.1
Fayetteville, Ark.	1010-1121	59.6-62.1	6.7-6.9

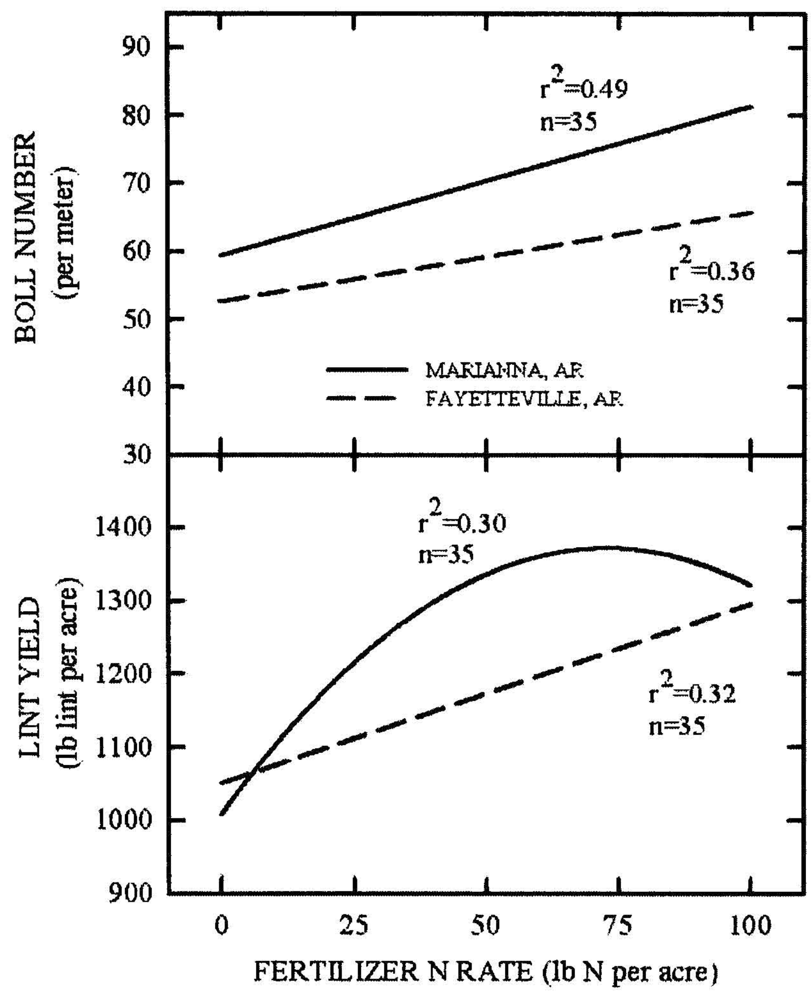

Fig. 1. Response of boll number and lint yield to fertilizer N rate during the 2012 growing season.

Response of Canopy Nitrogen Stress Indices to Variety and Available Potassium

T.B. Raper, D.M. Oosterhuis, L. Espinoza, C. Pilon, and J. M. Burke

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Recent advances in technology and the increased availability of canopy reflectance hardware has resulted in the development and utilization of vegetation indices to drive on-the-go variable rate applications of fertilizer nitrogen (N). Although the spectral response of crops to N stress has been thoroughly defined (Samborski et al., 2009), the spectral response to differing varieties and available potassium (K) quantities have not been examined in such detail. As a result, sensitivities of these indices to variables other than N deficiency have been shown to result in over application of N when N is not the most limiting yield factor (Zillman et al., 2006).

Leaf reflectance measured by a spectrometer is typically sensitive to changes in N status; however, research has shown a deterioration of this relationship when K is not sufficient (Fridgen and Varco, 2004). Further complicating sensor-driven, variable rate applications of N is that K deficiency symptoms may appear, especially during fruiting (Oosterhuis and Weir, 2010) on soil that has a sufficient soil-test K level (Cope, 1981). Moreover, the large spectrum of varieties in upland cotton production encompasses vastly different structural features and physiological maturity patterns. The most frequently utilized index, normalized vegetation difference index (NDVI), has been reported to be sensitive to variety during the flowering period, with relationships deteriorating later in the growing season (Benitez Ramirez and Wilkerson, 2010).

Although neither the response to variety nor available K is typically considered in the development of a canopy reflectance-based, N-sensitive index, the responses of each index to these variables must be considered to prevent inaccurate N fertilization and subsequent environmental and financial repercussions. Therefore, the main objective of this research was to examine the response of two contrasting indices to variety and changes in available K.

PROCEDURES

A randomized strip, complete block trial with five replications was conducted in 2012 at the Lon Mann Cotton Research Center in Marianna, Ark. Soil samples were taken from each plot (60 total plots) on 31 January 2012 and analyzed (Mehlich-3 extraction) by the University of Arkansas Soil Testing Laboratory in Marianna, Ark. Treatments consisted of an untreated check (0 lb K_2O/acre), 30, 60, and 90 lb K_2O/acre applied to Phytogen 499 WRF, Stoneville 5458 B2RF, and DeltaPine 912 B2RF varieties. Cotton was planted on 8 May 2012 at a plant density of 3.5 plants/foot. All other inputs and thresholds were established and maintained to isolate K as the sole yield-restricting input.

Reflectance measurements were taken on two dates (7 and 22 August 2012) after visible deficiency characteristics were evident using the Crop Circle ACS-470 (Holland Scientific Inc., Lincoln, Neb.). The three measured wavelengths were centered in the red (650 nm), red-edge (670 nm), and near infrared (760 nm) regions. These wavelengths were then used to calculate two contrasting indices: NDVI, which has been shown to be sensitive to changes in plant structure and biomass (Bronson et al., 2003), and the Canopy Chlorophyll Content Index (CCCI) which has a heightened sensitivity to N stress and is less responsive to changes in plant biomass than NDVI (Raper and Varco, 2011).

Regression analysis tested the response of seedcotton yield and index readings to changes in available K_2O. Analysis of variance was conducted for both reflectance dates and yield data in JMP 10 (SAS Institute Inc., Cary, N.C.). Independent variables in the model included block, available K, variety, and the interaction between available K and variety. The calculated amount of available K was chosen in lieu of the applied K fertilizer rate due to initial differences in soil K concentrations (Table 1). Available K_2O was calculated as [(ppm soil-test K $\times$ 2 $\times$ 1.2) + lb K_2O fertilizer/acre] where 1.2 is the factor for converting K to K_2O and 2.0 is the factor for converting ppm to lb/acre assuming 2 million pounds soil/acre furrow slice.

RESULTS AND DISCUSSION

The response of seedcotton to changes in variety and available K_2O were significant ($P \leq 0.05$), as was the interaction between these two terms ($P \leq 0.10$) (Fig. 1). Results suggest increases in available K_2O did not significantly increase Phytogen 499 seedcotton yields, but did increase DeltaPine 912 and Stoneville 5458 yields. As evident by the available K_2O levels and relatively high yields, severe K deficiencies were not noted. Sufficient soil K may have contributed to the failure of Phytogen 499 yields to respond to increased available K_2O. Still, the moderately strong response of Stoneville 5458 and slight response of DeltaPine 912 does suggest that increased K_2O availability could increase yields within this range for these two varieties.

Visible K deficiency symptoms were noted during the first week of flower in Stoneville 5458 plots but were not consistent across the field until near peak flower. As a result, reflectance was measured at mid-flower (7 August 2012) and after peak flower (22 August 2012). Responses from both sampling dates were similar. The interaction effects between available K_2O and variety on NDVI readings were significant ($P \leq 0.10$) (Fig. 2). However, CCCI was significantly affected only by variety, as available K_2O had no significant effect on CCCI ($P \leq 0.05$, Fig. 2).

Results suggest NDVI is sensitive to variety and changes in available K_2O. The interaction between variety and available K_2O suggests that individual models will have to be developed to characterize specific NDVI response to an individual variety's sensitivity to changes in available K_2O. In contrast, CCCI was only significantly affected by variety, which suggests that a variety specific correction term could be developed and implemented. It should be noted that significant response of an index to variety should be highly preferred over the response of an index to available K_2O, because variety is spatially consistent.

PRACTICAL APPLICATIONS

The adoption of on-the-go sensor readings to drive variable rate N applications must incorporate some correctional factor for variety if NDVI or CCCI is used. Furthermore, it appears that NDVI-based algorithms have the potential to recommend increased fertilizer N when K deficiencies are present. In contrast, CCCI does not appear to be susceptible to such errors.

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Table 1. Soil-test K (Mehlich-3) results and calculated available K_2O concentrations from soil samples taken January 2012 in Marianna, Ark.

	Mehlich-3-extractable soil potassium (ppm)		
Replication	Min	Mean	Maximum
1	63	86	135
2	67	95	133
3	96	122	139
4	80	109	147
	Calculated available soil potassium (lb K_2O/acre)[a]		
Replication	Min	Mean	Maximum
1	181	259	349
2	160	258	349
3	260	341	391
4	232	316	442

[a] Calculated available soil K represents a conversion of soil parts per million (ppm) to lb of available K_2O per acre added to lb of applied K_2O fertilizer, with 100% availability of applied fertilizer assumed.

Table 2. Coefficient of determinations (r^2) for response of the Normalized Difference Vegetation Index (NDVI) and the Canopy Chlorophyll Content Index (CCCI) by variety to changes in available K_2O.

	Coefficient of determination (r^2)			
	Canopy Chlorophyll Content Index (CCCI)		Normalized Difference Vegetation Index (NDVI)	
Variety	7 Aug	22 Aug	7 Aug	22 Aug
DeltaPine 912	0.000	0.001	0.004	0.046
Phytogen 499	0.056	0.019	0.090	0.069
Stoneville 5458	0.038	0.086	0.064	0.122

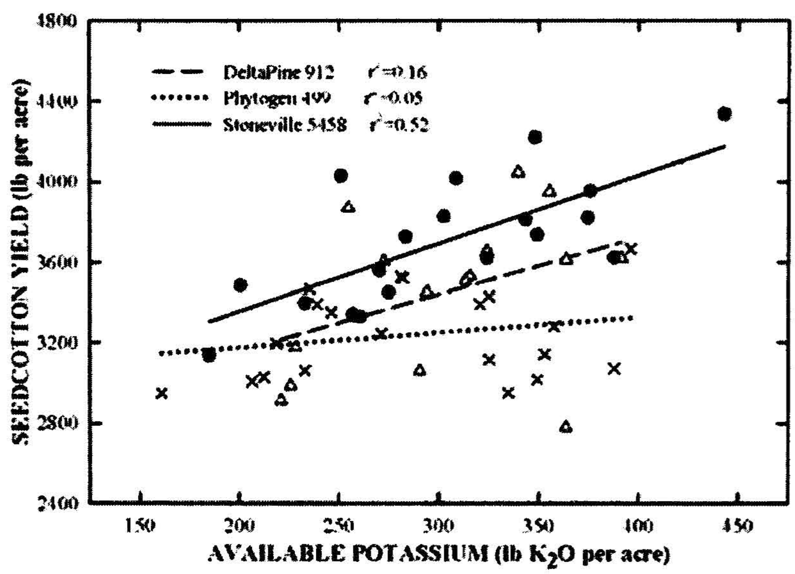

Fig. 1. Response of mean seedcotton yield to the average available K_2O during the 2012 growing season.

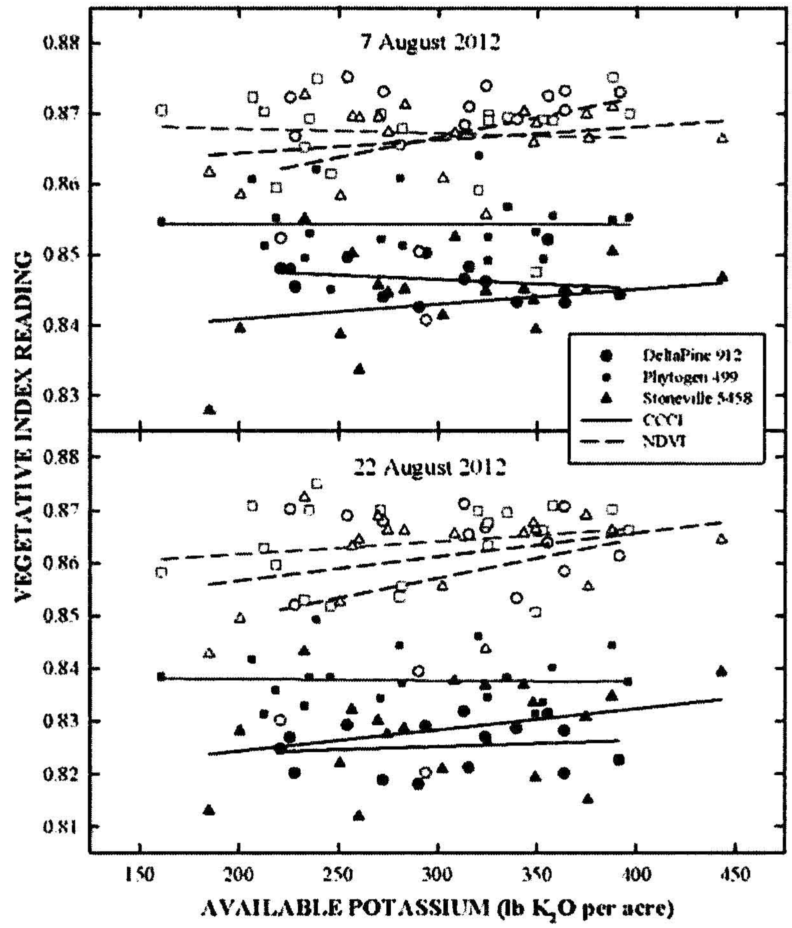

Fig. 2. Response of the mean Normalized Difference Vegetation Index (NDVI) and the Canopy Chlorophyll Content Index (CCCI) by variety to changes in mean available K_2O.

Wheat and Double-crop Soybean Yield Response to Phosphorus and Potassium Fertilization

N.A. Slaton, R.E. DeLong, C.G. Massey, S. Clark, J. Shafer, and J. Branson

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soft red winter wheat (*Triticum aestivum* L.) is grown in rotation with soybean [*Glycine max* (L.) Merr.] and grain crops in Arkansas. Farmers often examine crop and production input prices when deciding whether to grow wheat and follow with double-crop or full-season soybeans. The most recent statistics including double-crop soybean production show 610,000 to 750,000 acres were harvested in 2007 and 2008, respectively, with average yields of 33 to 34 bu/acre (USDA-NASS, 2008). Double-crop soybeans once accounted for about 22% of the Arkansas soybean acres and 75% to 87% of the harvested wheat acres.

The influence that wheat production has on the phosphorus (P) and potassium (K) nutritional requirements and yield potential of the following soybean crop are of interest since fertilizer costs and yield potential are important components of crop profitability. Our primary objectives were to determine wheat grain yield response to P and K fertilization rate, evaluate how nutrient uptake and removal of wheat grown for grain influences soybean response to P and K fertilization, evaluate soybean response to fall and spring fertilizer application, and compare soil-test P and K values from samples collected at three different times.

PROCEDURES

In fall 2011, trials were established at the Lon Mann Cotton Research Station (LMCRS) on a Convent silt loam and the Pine Tree Research Station (PTRS) on a Calloway silt loam both following soybean. Each site had two adjacent plot areas designated for the P or K trial. Each experiment contained three factors including fertilizer rate (0, 50, 100, and 150 lb K_2O/acre or 0, 40, 80, and 120 lb P_2O_5/acre), P and K application time (fall, before planting wheat; or spring, after wheat harvest) and wheat management (cover crop or grain). Wheat that was grown as a cover crop received no N fertilizer and was killed with glyphosate, applied with a rolling applicator, at Feekes stage 7.0 on 19 March 2012. Each trial contained 16 treatments arranged as a randomized complete block (RCB) design with a 4 (rate) by 2 (time) by 2 (wheat) factorial arrangement in each of five blocks.

Two composite soil samples (0- to 4-in. depth) were taken in each block from the plots designated to receive no fertilizer with different wheat management practices (cover crop or wheat for grain) to determine mean soil chemical properties. Soil samples were collected from these plots in the fall within one week of the wheat planting date, late February, and late May, following wheat harvest. For the May sampling, composite samples were also collected from two additional plots in each block which included plots that received 80 lb P_2O_5 or 100 lb K_2O/acre from each of the wheat management treatments. Soil was oven-dried at 130 °F, crushed, and passed through a 2-mm sieve for measurement of Mehlich-3 extractable nutrients, organic matter by weight loss on ignition, and soil water pH. Mean values of selected soil chemical properties are listed in Table 1.

AgriPro Coker 9553 wheat was drill-seeded (100 to 120 lb seed/acre) into conventionally tilled beds spaced 38 in. apart on 21 October at the LMCRS. Armor Ricochet wheat was drill-seeded (100 to 120 lb seed/acre) into a conventionally tilled seed bed on 25 October at the PTRS. Individual plots were 20 ft long and 13 ft wide at the PTRS and 22 ft long by 12.7 ft wide at LMCRS with 7.5- and 7.0-in. wide rows, respectively.

Fertilizer treatments were broadcast by hand to the soil surface of each plot within one week after planting wheat for the fall application and on 22 May at LMCRS and 5 June at the PTRS for the spring application following wheat harvest at each site. Each P rate trial included the rates of 0, 40, 80, and 120 lb P_2O_5/acre applied as triple superphosphate. Potassium fertilizer (100 lb muriate of potash/acre) was broadcast-applied to P trials on the same date as fall and spring treatments were applied to ensure that K was not yield limiting. A total of 140 lb N/acre was applied as urea in two equal splits made on 27 February and 19 March. At maturity, grain yields were measured by harvesting all 16 rows of each plot with a small-plot combine at PTRS and 8 rows at LMCRS. Grain yields were adjusted to a uniform moisture content of 13%.

Soil-test data were subjected to two analysis of variance (ANOVA) procedures. First, data collected at three different times from plots receiving no fertilizer and subjected to different wheat stand management practices (cover or grain) were analyzed as a RCB with a split-plot structure where sample time was the subplot. The objective of this analysis was to determine how wheat management influenced soil-test parameters across time. The second ANOVA was to evaluate how wheat management and nutrient rate influenced soil-test parameters from samples collected in May 2012.

Wheat yield data was analyzed as a RCB design of four nutrient rates with each trial having five blocks. Wheat growing in plots that were to receive P or K fertilizer after wheat harvest were considered as extra observations (n = 20) of 0 lb P_2O_5 or K_2O/acre. Thus, mean yields were based on either five (50, 100, and 150 lb K_2O or 40, 80, or 120 lb P_2O_5/acre) or 25 (0 lb P_2O_5 or K_2O/acre) observations. All ANOVA were performed with the Mixed procedure in SAS v. 9.2 (SAS Institute, Inc., Cary, N.C.). When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference method at a significance level of 0.10.

Soybean was seeded in 15- or 38-in. wide rows on 31 May at LMCRS (Armor 55-R22) and 5 June at the PTRS (Armor 48-R40), respectively, into untilled seedbeds following wheat harvest. At LMCRS, the field was irrigated following wheat harvest to soften the beds and enhance soil conditions for obtaining a uniform stand on top of the beds. At PTRS, the research areas laid fallow waiting for rain to improve seedbed conditions. The post-wheat harvest P and K fertilizer applications were made following wheat harvest and soil sample collection as described previously. Soybean at the PTRS had to be replanted as the rainfall received before planting was not sufficient for uniform emergence. The existing soybean stand was killed and Pioneer 94Y46 soybean was replanted on 26 June. Soybean was irrigated and treated for pests as needed during the season.

Recently matured trifoliate leaf samples were collected (12 to 15/plot) at the R2 stage, dried, ground, digested, and analyzed for nutrient concentrations. Tissue analysis has not yet been completed and will not be summarized in this report. The treatment structure of the soybean trials was a split-split plot where nutrient rate was the whole plot, fertilizer application time was the subplot, and wheat management was the sub-subplot. Soybean receiving no P or K fertilizer (control) was not included in the ANOVA, which was performed by site using the same procedures and interpretation parameters as described for soil and wheat. Single-degree-of-freedom contrasts were used to compare the yield of soybean receiving no fertilizer against yields produced by the two highest fertilizer rates to assess whether P or K fertilization had any overall benefit to yield ($P < 0.10$).

P Source Trial

One additional wheat experiment was established on a Calloway silt loam following soybean at the PTRS to examine wheat yield response to different P fertilizer sources. A composite soil sample was collected from the 0- to 4-in. depth from each replicate within one week of planting (Table 1). Ricochet wheat was drilled seeded on 2 November and managed (in regard to K and N fertilizer) as described for the PTRS wheat double-crop soybean trial.

The fertilizer treatments consisted of four P fertilizer sources including monoammonium phosphate (MAP, 11-52-0), MicroEssentials (MESZ, 12-40-0-10S-1Zn), triple superphosphate (TSP, 0-46-0), and preplant N with each P source applied at rates of 35, 70, and 105 lb P_2O_5/acre. The preplant N treatment was three rates of ammonium sulfate applied at N rates that equaled the amount of N applied as each rate of MAP. Each block also contained three no P and N controls. All P fertilizers were applied to the soil surface on 2 December following wheat emergence. Harvest and ANOVA were performed as described previously.

RESULTS AND DISCUSSION

Site Descriptions

The soil-test P level associated with the average Mehlich-3 extractable P at each site was classified as 'Low' (16 to 25 ppm) at the PTRS-P and 'Medium' (26 to 35 ppm) at LMCRS-P (Table 1). Based on the University of Arkansas Cooperative Extension Service fertilizer guidelines for winter wheat, 60 and 50 lb P_2O_5/acre would have been recommended for the Low and Medium soil-test P levels with little or no yield increase expected at LMCRS-P. Soil-test P in the wheat P source trial was interpreted as Low.

For the K trials, both sites had 'Medium' (91 to 130 ppm K) soil-test K levels and 60 lb K_2O/acre would have been recommended for wheat. A limited amount of previous research has shown little or no yield increase from K fertilization of wheat grown on soils having Medium K availability, but soybean grown following wheat is usually responsive to K fertilization.

Soil Responses to Fertilization Time, Rate, or Wheat Management

Soil-test P and K values of soil receiving no P or K fertilizer changed among sample times (P-value < 0.05), averaged across wheat management systems at both sites (Table 2). However, there was no difference in soil-test P between wheat management systems (P-value ranged from 0.3827 to 0.9651). The soil sample time by wheat management interaction was significant only for K at the LMCRS (Table 2). In general, soil samples collected in October 2011 and March 2012 had similar soil-test P that was greater than samples collected in May 2012 following wheat harvest, regardless of wheat management. At the PTRS, soil-test K declined with each sample time. At the LMCRS, soil-test K varied among sample times and wheat management systems with the general trend to decline as sample time was delayed. At the LMCRS, soil-test K values were comparable between wheat management systems except following wheat harvest when soil-test K was lowest in soil where wheat was harvested for grain.

Soil-test P and K values from samples collected following wheat harvest were always affected by the fall-applied P and K fertilizer rate ($P < 0.05$), but the wheat management by fertilizer rate interaction was significant only for soil-test K at the LMCRS (Table 3). The interaction showed that soil-test K was lower in soil where wheat was harvested for grain and that fall-applied K fertilizer increased soil-test K with the magnitude of the differences changing between K rates. In all other cases, soil-test P or K, changed in response to fertilization, but not wheat management. Although not statistically significant, soil-test K at the PTRS showed a similar trend as the LMCRS. The results suggest that the Mehlich-3 soil-test method is sensitive enough to detect labile soil nutrients that are removed via winter wheat uptake and a portion of the nutrients added in fertilizer, but soil-test values may fluctuate by 4 or 5 ppm for P and 15 to 50 ppm for K compared with samples collected in the fall.

Wheat Yield Response to Fertilization

Wheat grain yields were not significantly affected by P or K fertilization in these trials (Table 4). This is not overly surprising for K since soil-test K was classified as 'Medium' at each site (Table 1). The most up-to-date correlation between relative wheat grain yield and soil-test P suggests that the critical soil test is 35 ppm P and soil-test values of 18 and 28 ppm would produce relative yields of 87% and 92% (± 3.5% standard error) of maximum (maximum = 95%), respectively. Thus, the expected yield increase from P fertilization was expected to be less than 10%. Prior research has shown that wheat following soybean is less responsive to P than when wheat follows rice or another grain crop that may produce large amounts of residue that might immobilize soil P.

Wheat Yield Response to P Source and Rate

Wheat yield was not affected by P_2O_5 rate (P = 0.1959) or the source by rate interaction (P = 0.7974), but the main effect of P source was significant (P = 0.0535, not shown). Wheat receiving no P or N in the fall produced the lowest yield (94 bu/acre, LSD0.10 = 5 bu/acre) and was not different from the yields of TSP (96 bu/acre) and MAP (99 bu/acre). Wheat fertilized with MESZ (104 bu/acre) and preplant N (102 bu/acre) produced the greatest yields suggesting that the extra N added had a greater effect on yield than P. The P rate yield means support this conclusion since yields tended to increase as P rate, and hence N rate, increased.

Soybean Yield Response to Fertilization

The yield of double-crop soybeans at the LMCRS was significantly affected by significant 2-way interactions involving K fertilization time × rate and fertilization time × wheat management (Table 5). In general, soybean yields were numerically lowest when no K was applied and numerically greatest when 100 or 150 lb K_2O/acre was applied. The wheat management × fertilizer application time interaction showed that soybean following wheat grown as a cover crop tended to produce greater numerical yields than soybean following wheat grown for grain. The only significant difference among soybean yields in this interaction was that K fertilizer applied in the fall to grow wheat as a cover crop produced a greater soybean yield than the other three treatment combinations. Overall, application of 50 to 150 lb K_2O/acre resulted in a 4 bu/acre soybean yield increase at the LMCRS-K site.

Only wheat management had a significant influence on soybean yield at the PTRS (Table 6). In both trials soybean yields were greater, albeit by 2 bu/acre, when soybean followed wheat grown as a cover crop. Single-degree-of-freedom contrasts showed that K fertilization (yield average of 100 and 150 lb K_2O/acre) increased the yield of soybean receiving no K fertilizer by an average of 3 bu/acre.

In both P trials, only wheat management significantly affected the yield of the double-crop soybean (Table 6). Soybean yields, averaged across P rates and application times, were greatest following wheat grown as a cover crop and lowest following wheat harvested for grain. This was the opposite of what was found at both sites in the first year of research. The lack of soybean yield response to P fertilization is not surprising since our previous research has shown limited yield benefits from P fertilizer. The correlation relationship suggests that the critical soil-test P is 20 ppm (not shown). Phosphorus fertilization rate, averaged across application times and wheat management systems, had no significant effect on soybean yield.

PRACTICAL APPLICATIONS

Wheat and double-crop soybean yields were not affected by P fertilization in these trials. Wheat yields were also unaffected by K fertilization. Soybean yields were increased significantly or numerically depending on the site-year only by K fertilization. The results indicate that double-crop soybean yield is not greatly affected by fertilizer application time, but can be influenced by land management (winter fallow/cover crop or wheat for grain). Soil-test P and K values changed from the fall to early summer in response to soil sample time (temporal variation), wheat management, and/or fertilization rate. The significant temporal changes in soil-test values make development of accurate fertilizer recommendations more challenging. The temporal changes tend to be more dramatic for K than for P.

Wheat management system has consistently influenced soybean yields for the two years that we have conducted this trial. Each year the system that has produced the greatest yield has been different and may reflect differences in annual weather and field conditions. That said, the soybean yield difference has been relatively small each year. The main purpose of the trial was to characterize whether growing and harvesting wheat for grain production (compared to as a cover crop) influenced how much P or K fertilizer is needed. Our results suggest that double-crop and full-season (planted at same time) soybean seldom respond to P fertilization. The wheat-soybean production system has not changed how soybean yields respond to K fertilizer suggesting that K fertilizer rates for full-season soybean should also be optimal for double-crop soybean.

LITERATURE CITED

(USDA-NASS) United States Department of Agriculture, National Agricultural Statistics Service. 2008. Arkansas Crop Statistics - County estimates by year (On-line). Available at http://www.nass.usda.gov/Statistics_by_State/Arkansas/Publications/County_Estimates/index.asp. Washington, DC.

Table 1. Selected soil chemical property means (n = 10) from soil samples collected in October 2011 in P and K fertilization trials with winter wheat and double-cropped soybean conducted at the Lon Mann Cotton Research Station (LMCRS) and the Pine Tree Research Station (PTRS) during the 2011-2012 growing season.

Site	SOM	Soil pH	P†	K†	Ca	Mg	S	Na	Fe	Mn	Zn	Cu
			Mehlich-3 extractable soil nutrients									
	(%)		(ppm)									
LMCRS-P*	1.78	5.8	28	121	750	132	12	9	168	155	1.1	1.9
PTRS-P	2.36	7.3	18	111	1431	236	19	45	168	382	1.1	1.4
PTRS-PS	3.15	7.6	22	93	1832	276	12	22	350	532	2.2	1.7
LMCRS-K	1.65	5.7	28	114	814	156	12	10	158	138	1.2	1.4
PTRS-K	2.46	7.5	15	118	1498	251	20	43	154	433	1.1	1.3

* P = phosphorus; K = potassium; and PS = phosphorus source.

† Standard deviation of soil-test P in P trials was 4.2 ppm for LMCRS-P, 2.5 ppm for PTRS-P, and 1.0 ppm for PTRS-PS and soil-test K in K trials was 7.5 ppm for LMCRS-K and 21 ppm for PTRS-K.

Table 2. Soil-test P and K means (for soil receiving no fertilizer) as affected by soil sample time, wheat management, or their interaction at the Pine Tree Experiment Station (PTRS) and Lon Mann Cotton Research Station (LMCRS) during 2011-2012. Soil-test P data is from the P trials and soil-test K data is from the K trials.

Site	Soil sample time	Wheat management* Cover crop	Grain	Cover crop	Grain
		(ppm P)		(ppm K)	
PTRS	October 2010	18	18	116	120
	March 2012	18	18	99	97
	May 2012	15	14	78	73
	P-value	0.1717		0.7703	
LMCRS	October 2011	28	29	111 Aa	116 Aa
	March 2012	27	28	100 Ab	101 Ab
	May 2012	25	26	96 Ab	85 Bc
	P-value	0.9936		0.0119	

* For data with a significant 2-way interaction, the lowercase letters compare any two means and uppercase letters compare means between wheat management systems within each sample time. Only the main effect of soil sample time, averaged across wheat management system, was significant for the PTRS and LMCRS soil-test P and PTRS soil-test K.

Table 3. Soil-test P and K means as affected by fertilizer rate and wheat management for soil samples collected in June 2012 at the Lon Mann Cotton Research Station (LMCRS) and Pine Tree Research Station (PTRS). Soil-test P data is from the P trials and soil-test K data is from the K trials.

Site	Nutrient rate*	Wheat management			
		Cover crop	Grain	Cover crop	Grain
	(lb P_2O_5 or K_2O/acre)	(ppm P)		(ppm K†)	
PTRS	0	15	14	78	73
	80 or 100	20	20	126	118
	P-value	0.3559		0.7837	
LMCRS	0	25	26	96 b	85 c
	80 or 100	36	33	125 a	103 b
	P-value	0.3559		0.0744	

* Phosphorus applied at 80 lb P_2O_5/acre and potassium applied at 100 lb K_2O/acre.
† For data with a significant 2-way interaction, lowercase letters compare any two means.

Table 4. Wheat grain yield as affected by P or K fertilizer rate at the Lon Mann Cotton Research Station (LMCRS) and the Pine Tree Research Station (PTRS) during the 2011-2012 growing season.

Nutrient rate	Phosphorus trials		Nutrient rate	Potassium trials	
	LMCRS	PTRS		LMCRS	PTRS
(lb P_2O_5/acre)	(bu/acre)		(lb K_2O/acre)	(bu/acre)	
0	56	92	0	56	91
40	57	91	50	57	85
80	55	96	100	55	98
120	56	92	150	54	91
LSD0.10	NS*	NS	LSD0.10	NS	NS
P-value	0.8994	0.5331	*P*-value	0.8055	0.1080
C.V., %	7.8	5.5	C.V., %	8.2	8.4
SDF contrast†	0.9669	0.7391	SDF contrast	0.7050	0.9582

* NS = not significant ($P > 0.10$).
† SDF = single-degree-of-freedom contrast comparing the yield wheat fertilized with P (40, 80, and 120 lb P_2O_5/acre) against wheat receiving no P.

Table 5. Double-crop soybean yield as affected by the two-way interactions between K fertilizer rate and K application time, averaged across wheat management, and wheat management and K fertilizer application time, averaged cross K application rate, at the Lon Mann Cotton Research Station (LMCRS) in 2012.

Fertilizer time	K rate (lb K_2O/acre)				Wheat management	
	0	50	100	150	Cover crop	Grain
	(bu/acre)					
Fall	60 b*	64 ab	65 ab	67 a	67a	61 b
Spring	61 b	65 ab	65 ab	62 b	64 b	63 b
P-value	0.0586				0.0536	

* Means within a column followed by the same lowercase letter are different at the 0.10 level.

Table 6. Double-crop soybean yield as affected by the main effect of wheat management, averaged across nutrient rates and fertilizer application times, in four nutrient trials conducted at the Lon Mann Cotton Research Station (LMCRS) and Pine Tree Research Station (PTRS) in 2012.

Wheat management	LMCRS		PTRS	
	P trial	K trial	P trial	K trial
	(bu/acre)			
Cover crop	71 a*	66 a	53 a	51 a
Grain	67 b	62 b	51 b	49 b
P-value	0.0103	0.0037	<0.0001	0.0043

* Means within a column followed by the same lowercase letter are different at the 0.10 level.

Soybean Response to Fertilization and/or Foliar Amendment

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Soil testing is used to identify soils that are nutrient deficient and to recommend how much of each deficient nutrient should be applied to optimize crop yield, maintain soil fertility, or both. The University of Arkansas Cooperative Extension Service uses the Mehlich-3 soil-test method to assess soil phosphorus (P) and potassium (K) availability. Our research efforts have demonstrated that the Mehlich-3 method does an adequate job of estimating soil K availability (Slaton et al., 2010), but the accuracy of recommendations based on soil-test P is less than desired. Specifically, Mehlich-3 soil-test P appears to accurately predict sufficient soil P availability when soil-test P is above 25 to 30 ppm, but is not accurate on soils with <25 to 30 ppm P. Other land grant universities provide fertilizer recommendations based on the Mehlich-3 soil-test method and, in general, their critical soil-test P values are in close agreement with those used by the University of Arkansas Cooperative Extension Service.

One long-term goal of our soybean research program is to build a database to develop and/or refine soil-test-based fertilizer recommendations for P and K. Our short-term research objective is to evaluate soybean responses to P and K fertilizer rates on soils with a range of soil P availability index values. To achieve this objective, we collected soybean data from one-year trials (rate trials in new fields) and from ongoing trials that receive the same fertilizer rates annually. Our current research has focused on enhancing our P recommendations.

PROCEDURES

Phosphorus and K fertilization trials with soybean were established at the Pine Tree Research Station (PTRS), Rice Research and Extension Center (RREC), and one grower field in Cross County during 2012. Specific soil and agronomic information for each site is listed in Table 1. Each location will be referred to by the site name listed in Table 1. Management with respect to seeding rate, irrigation, and pest control at all sites closely followed recommendations from the University of Arkansas Cooperative Extension Service. In each trial, soybean was flood irrigated as needed.

At each site, individual plots were 16- to 25-ft long by 6.5- to 15-ft wide. Before fertilizer was applied to the research tests, a composite soil sample was collected from the 0- to 4-in. depth from each replicate (n = 6-8). Soil samples were oven-dried at 130 °F, crushed, and passed through a 2-mm sieve. Soil water pH was determined in a 1:2 soil weight:water volume mixture, plant-available nutrients were extracted using the Mehlich-3 method, and elemental concentrations in the extracts were determined using inductively coupled plasma spectroscopy (ICPS). Selected soil chemical property means are listed in Table 2. More specific details of each trial are provided in the following sections.

Rice Research and Extension Center P and K Trials

Annual soil samples were collected from each plot (0- to 4-in. depth) in March 2012, processed as previously described, and analyzed for soil pH and Mehlich-3 extractable nutrients. Armor 48-R40 soybeans were drill seeded into the previous year's rice stubble on 20 April 2012. Annual P (as triple superphosphate) and K (as muriate of potash) rates of 0, 40, 80, 120, and 160 lb P_2O_5 and K_2O/acre were applied to the soil surface shortly after soybean emergence. A maintenance application of P fertilizer (60 lb P_2O_5/acre) was applied to the K trial and K fertilizer (60 lb K_2O/acre) was applied to the P trial. Additional agronomic details of the experiment are given in Tables 1 and 2. Trifoliate leaf samples were collected on 5 July when plants were at the R4 growth stage (later than desired). Grain yield was measured at maturity. Each trial was a randomized complete block (RCB) design with six replications of each annual P or K rate.

Phosphorus Rate Trials

Trials were established at the PTRS and a grower field in Cross County (Cross-PSR) to evaluate the influence of P fertilizer source and rate on soybean yield. The PTRS-PSR trial was on a soil mapped as a Calhoun silt loam that followed soybean in the rotation and the Cross-PSR trial was on a soil mapped as a Henry silt loam that followed rice. Selected agronomic information and soil chemical property means are shown in Tables 1 and 2.

Each trial consisted of two P fertilizer sources including triple superphosphate (TSP, 0-46-0) and MicroEssentials

(MESZ, 12-40-0-10S-1Zn) applied at rates of 0, 40, 80, 120, and 160 lb P_2O_5/acre. The 0 lb P_2O_5/acre rate was treated as both a rate and a source (No P) in the analysis of variance (ANOVA). At both sites, the P fertilizer was applied to the soil surface shortly before or after the soybeans were planted. The treatments were arranged as a 2 (Sources) by 4 (rates) factorial plus a no P control with four (Cross-PSR) or five (PTRS-PSR) blocks.

Foliar Amendment Trials

Experiments aimed at evaluating the benefits of soil-applied P and K fertilizer and various foliar-applied products were established in field areas adjacent to the P source trials at the PTRS-PK and Cross County (Cross-PK) trials. Selected soil properties and management information are listed in Tables 1 and 2.

Each experiment contained similar treatments that consisted of standard soil-applied fertilizer treatments of 0 lb P_2O_5 plus 0 lb K_2O/acre and 60 lb P_2O_5 plus 80 lb K_2O/acre as triple superphosphate and muriate of potash. Each site also contained five foliar-applied treatments which will be referred to as the control (foliar applied B only), Foliar Blend (Agri-Gro Marketing, Inc., Doniphan, Mo.), Stoller Products (Stoller USA, Houston,, Texas), Perc Plus (3% N, 17% P_2O_5, 0.25% Cu, and 0.50% Zn; McRight Services, LLC, DeltAg Formulations, Greenville, Miss.), and ProTea Products (Protea Botan U.S., Inc., Collierville, Tenn.).

The control treatment consisted of a foliar application of B fertilizer. At the PTRS-PK site, Borosol-10 (10% B; Loveland Products, Inc., Greeley, Co.) was applied at a rate of 0.25 lb B/acre at the V3 stage on the same day that the other treatments were applied. The Borosol-10 product was also added as a tank mix partner with each additional product. At Cross-PK, the grower made a foliar B application to the entire field and no additional treatment was sprayed on the control plots at the V3 stage. The Stoller Products treatment included 8 oz BioForge/acre (N,N'-diformyl urea) applied at the V3 stage followed by 32 oz Sugar Mover/acre (8% B and 0.004% Mo) at the R1 stage. The Foliar Blend product was applied at 32 oz/acre/application with applications made at the V3 and R1 growth stages. Perc Plus is classified by its manufacturer as a 'biostimulant' and was applied at 16 oz/acre/application at the V3 and R1 stages. The ProTea products consisted of applying the product sold as SoyAstim-27 (5%N, 16% P_2O_5, 6% K_2O, 0.10% Fe, and ≤ 0.05% B, Cu, Mn, Mo, and Zn) at 32 oz/acre/application at the V3 and R1 growth stages. Additional information on each of these products can be obtained by visiting the manufacturer's web site. All applications were made with a CO_2 backpack sprayer calibrated to deliver 10 gal/acre at 3 mph. The V3 and R1 applications were made on 13 June and 18 July (R1) at Cross-PK and 23 May and 5 July at PTRS-PK. Trifoliolate leaf samples were collected before the second foliar application of product was applied to evaluate the effect of each product on leaf nutrient concentration. Each trial was a RCB with a 2 by 5 factorial treatment arrangement with four (Cross-PK) or five (PTRS-PK) blocks.

In all trials, the most recently matured trifoliate leaves (15) were collected at the R1 growth stage, dried to a constant moisture, ground to pass a 1-mm sieve, digested, and analyzed for elemental concentrations by ICPS. A 12- to 20-ft long section of the middle of each plot was harvested with a plot combine. Soybean moisture was adjusted to 13% for final yield calculations. For all studies, ANOVA was conducted by site with the GLM procedure in SAS v9.2 (SAS Institute, Inc., Cary, N.C.). When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference (LSD) method at a significance level of 0.10. In some trials, single-degree-of-freedom contrasts were used to compare selected treatments with significant differences identified when $P < 0.10$.

RESULTS AND DISCUSSION

Rice Research and Extension Center Long-term Trial

Pelleted lime (1,000 lb/acre) was broadcast to the RREC research area after soil samples were collected to increase soil pH. Thus, the soil chemical properties listed in Tables 2 and 3 are accurate for the time of soil sample collection, but soil pH likely increased in the following weeks. Five years of P and K fertilization and cropping have changed soil-test P and K availability (Table 3). Linear regression of the soil-test P and K means indicates that the soil-test P and K increases by 1 ppm for every 18.9 lb P_2O_5/acre and 10.5 K_2O/acre, respectively. Five years ago the mean soil-test P and K values of these two research areas was 17 ppm P and 148 ppm K suggesting that soil-test P in the no P control has not changed greatly but soil-test K availability has decreased substantially.

Despite the suboptimal soil-test P and K values in the unfertilized control, soybean yields were not changed by P or K fertilization in 2012 (Table 4). Trifoliolate leaf P and K concentrations from soybean grown in the 0 lb P_2O_5 or K_2O/acre treatments were considered low but not deficient. The low nutrient concentrations in leaf samples are likely because the samples were collected at the R4 stage, later than the intended (R2) growth stage. In the K rate trial, soybean receiving ≥40 lb K_2O/acre/year had tissue K concentrations >1.8% K which were considered sufficient and no yield response was expected.

P Rate Trials

Trifoliolate leaf P concentrations were influenced by P fertilizer rate, averaged across sources, at Cross-PSR (Table 5), and fertilizer source, averaged across rates, at both sites ($P <$ 0.03, not shown). At Cross-PSR, leaf P concentrations tended to increase as P rate increased. In regard to P fertilizer source, leaf P was greatest for soybean fertilized with MESZ (0.356% P, LSD0.10 = 0.011), intermediate when triple superphosphate was the source (0.343%) and lowest when no P was applied (0.329%). Soybean at the PTRS-PSR followed the same order but the leaf P concentrations were quite different (0.210% for

MESZ, 0.202% for triple superphosphate, and 0.191% for no P; LSD0.10 = 0.007).

Leaf P concentrations were considered deficient for all P rates at the PTRS-PSR trial and sufficient at the Cross-PSR site, albeit only slightly above the critical P level of 0.30% P suggested by Sabbe et al. (2000). The early-season drought stress visibly affected soybean growth at the PTRS-PSR and likely reduced uptake of P and other nutrients and resulted in a small yield difference between soybean that received P as compared to soybean that received no P fertilizer.

At Cross-PSR, the multiple means comparison suggested that soybean yield was affected by the interaction between P source and rate, but the interaction showed no consistent trend among treatments (Table 5). The single-degree-of-freedom contrasts indicated that soybean fertilized with P produced similar yields as soybean receiving no P. Neither P source (P = 0.7292) nor P rate (P = 0.8809) and their interaction (P = 0.3790) significantly affected soybean yield at PTRS-PSR.

Foliar Amendment Trials

Some plots (n = 5) at Cross-PK had stand loss from scald following the first irrigation and yields from these plots were omitted from the statistical analysis. All treatments had a minimum of three replicates for calculating the mean yield. Soybean at the PTRS-PK received only 0.38 in. of rain in June and suffered from drought stress from emergence until the first irrigation. Neither the foliar-applied product main effect (P = 0.9102 at Cross-PK and P = 0.3678 at PTRS-PK) nor the preplant fertilization by foliar product interaction (P = 0.8337 at Cross-PK and P = 0.6095 at PTRS-PPK) had a significant influence on soybean yield at Cross-PK or PTRS-PK, respectively (Table 6). The main effect of preplant fertilizer rate was significant for the PTRS-PK site (P < 0.0001), but not the Cross-PK site (P = 0.3618). At the PTRS-PK, averaged across the five foliar treatments (n = 25), soybean fertilized with 60 lb P_2O_5 and 80 lb K_2O/acre yielded 69 bu/acre compared to 62 bu/acre for soybeans receiving no preplant P and K. This same main effect was not significant at Cross-PK, but showed a non-significant trend for soybean receiving P and K (64 bu/acre) to produce numerically higher yields than the unfertilized soybean (62 bu/acre).

The nutrient concentration of trifoliate leaves collected at the R1 stage (before the second foliar application was made) were not affected by the main effect of foliar-applied product or the preplant fertilizer by foliar product interaction (not shown). These results show no evidence suggesting the foliar-applied products stimulated the uptake of nutrients from the soil. Furthermore, the amount of nutrients contained in the applied solutions was likely too small to influence leaf nutrient concentrations. For example, Perc Plus contains 17% P_2O_5, which when applied at 16 oz/acre supplies 0.0915 lb P or 0.21 lb P_2O_5/acre. Application of 60 lb P_2O_5 and 80 lb K_2O/acre increased trifoliate leaf K concentrations at both sites, but, otherwise, only Mg (both sites), Cu (Cross-PK), and B (PTRS-PK) were affected by preplant fertilizer rate (Table 7).

PRACTICAL APPLICATIONS

Phosphorus fertilization rate trials with soybean have been conducted on over 50 site-years since 2004. To date, the correlation between Mehlich-3 soil-test P and the relative yield of soybean receiving no P fertilizer is significant (P < 0.05) when examined with a linear plateau model but is not very strong (r^2 = 0.29). The relationship suggests that the critical soil-test P is about 20 ppm but may range from 13 to 27 ppm. Trial results continue to show that when soil-test P is > 20 to 25 ppm that a significant yield response to P fertilization is unlikely. Trials conducted in 2012 showed that yields were not affected by P source or rate at two site-years, but responded to P rate in the fifth year of a long-term trial.

Two trials examining soybean response to P and K fertilization rate with and without foliar-applied fertilizers or biostimulant products showed no benefit from the foliar applied biostimulants/fertilizers at either site. Significant yield increases from P and K fertilization were measured at one site and the second site showed a non-significant trend for yields to increase numerically from P and K fertilization. Thus, results from these two trials would suggest that supplying adequate P and K to maintain or build soil fertility may be a better investment than foliar-applied nutrient solutions. The benefits of foliar-applied solutions to soybean yield should be approached just like fertilizer rate trials in that numerous site-years of research are needed to determine the probability that a yield increase will occur from their application.

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Table 1. Selected soil and agronomic management information for P and K fertilization trials conducted in 2012.

Site (nutrient)*	Soil series	Cultivar	Previous crop	Tillage	Row width	Plant date
Cross-PSR	Henry	Armor 53-Z5	Rice	Stale	15	18 May
Cross-PK	Henry	Armor 53-Z5	Rice	Stale	15	18 May
RREC-LTP	Dewitt	Armor 48-R40	Rice	No-till	7.5	20 April
RREC-LTK	Dewitt	Armor 48-R40	Rice	No-till	7.5	20 April
PTRS-PSR	Calhoun	Armor 53-R15	Soybean	Conventional	15	24 April
PTRS-PK	Calhoun	Armor 53-R15	Soybean	Conventional	15	24 April
PTRS-Ptime	Calloway	Armor 48-R40	Soybean	No-till	15	26 April
PTRS-Ktime	Calloway	Armor 48-R40	Soybean	No-till	15	26 April

* P = phosphorus, K = potassium, PSR = P source and rate, and LT = long-term.

Table 2. Selected soil chemical property means (n = 4-6) of soil from the unfertilized control in P and K fertilization trials conducted at multiple sites during 2012.

Site (nutrient)	Soil OM	Soil pH	Mehlich-3 soil nutrients P	K	Ca	Mg	S	Fe	Mn	Zn	Cu
	(%)		(ppm)								
Cross-PSR	2.3	7.0	30*	76	1517	236	48	238	68	6.6	0.7
Cross-PK	2.59	6.9	33*	72†	1542	240	45	248	74	7.5	1.1
RREC-LTP	2.3	5.4	--‡	119	841	127	13	550	162	6.2	1.0
RREC-LTK	2.3	5.1	36	--‡	659	103	13	647	121	5.8	0.9
PTRS-PSR	2.4	7.1	10*	70	1647	304	10	236	362	2.1	1.2
PTRS-PK	2.4	7.2	11*	72†	1678	301	9	250	356	2.3	1.2

* The standard deviation of soil-test P means is < 2.5 ppm for Boone-PSR, < 2.0 ppm for Boone-PK, 1.5 ppm for PTRS-PSR, and < 1.0 ppm for PTRS-PK.

† The standard deviation of soil-test K means is < 4 ppm Boone-PK and < 2 ppm for PTRS-PK.

‡ Soil-test P and/or K means for each annual P or K rate from the RREC trials are listed in Table 3.

Table 3. Mehlich-3 extractable soil-test P or K means as affected by annual P or K fertilization rate for two multi-year trials from samples collected in March 2012 at the Rice Research and Extension Center (RREC) in 2012.

Annual nutrient rate	P rate trial	K rate trial
(lb K_2O or P_2O_5/acre)	(ppm P)	(ppm K)
0	13	105
40	22	126
80	30	142
120	44	156
160	55	185
LSD0.10	5	12
P-value	<0.0001	<0.0001
Linear slope*	0.053	0.095

* Slope values represent the soil-test P and K values (shown above) regressed against the cumulative amount of each fertilizer applied since 2007 (multiply annual rates by 5) and has units of ppm soil-test P or K/ lb P_2O_5 or K_2O applied over the 5-year period.

Table 4. Trifoliate leaf P or K concentration and seed yield of soybean as affected by annual P or K fertilization rate for multi-year trials conducted at the Rice Research and Extension Center (RREC) in 2012.

Annual nutrient	RREC-P trial		RREC-K trial	
rate	Leaf P	Seed yield	Leaf K	Seed yield
(lb K_2O or P_2O_5/acre)	(% P)	(bu/acre)	(% K)	(bu/acre)
0	0.292	76	1.67	58
40	0.325	80	1.87	62
80	0.337	86	1.91	63
120	0.348	78	1.89	61
160	0.340	82	2.01	61
LSD0.10	0.27	5	0.07	NS*
P-value	0.0156	0.0225	<0.0001	0.6679
SDF †	0.0009	0.0208	<0.0001	0.1907

* NS = not significant (*P* > 0.10).

† SDF = single-degree-of-freedom contrast comparing the yield of soybean receiving no P or K fertilizer against the mean yield of soybean fertilized with 80, 120, and 160 lb P_2O_5 or K_2O/acre.

Table 5. Trifoliate leaf P concentration and seed yield of soybean as affected by P fertilization rate or the P rate by fertilizer source interaction for soybean grown at the Pine Tree Research Station (PTRS-PSR) and a commercial field in Cross County (Cross-PSR) during 2012.

	Cross-PSR			PTRS-PSR	
P-fertilizer		Seed yield			
rate	Leaf P	TSP*	MESZ*	Leaf P	Seed yield
(lb P_2O_5/acre)	(% P)	(bu/acre)		(% P)	(bu/acre)
0	0.33	74		0.19	65
40	0.34	77	73	0.20	68
80	0.34	71	77	0.21	69
120	0.35	74	74	0.20	68
160	0.37	78	73	0.21	68
LSD0.10	0.01	4		0.01	3
P-value	0.0030	0.0085		0.2937	0.8809
SDF†	0.0044	0.7850		0.0013	0.067

* TSP = triple superphosphate (46% P_2O_5); and MESZ = Microessentials fertilizer (40% P_2O_5).

† SDF = single-degree-of-freedom contrast comparing the yield of soybean receiving no P fertilizer against the mean yield of soybean fertilized with 80, 120, and 160 lb P_2O_5/acre.

Table 6. Soybean yield as affected by P and K fertilization rate and foliar-applied treatments at the Cross County (Cross-PK) and Pine Tree Research Station (PTRS-PK) sites during 2012.

	Cross-PK		PTRS-PK	
Foliar treatment*	0-0†	60-80†	0-0	60-80
	(bu/acre)			
Control	61	64	63	71
Perc Plus	63	64	60	66
SoyAstim-27	62	68	60	69
Stoller Products	62	60	63	70
Foliar Blend	61	65	64	67
LSD0.10	NS ‡		NS	
P-value	0.8337		0.6095	

* Foliar treatments: Control, boron only; Perc Plus, 16 oz/acre/application at the V3 and R1 stages; Stoller Products, 8 oz BioForge/acre applied at V3 stage followed by 32 oz Sugar Mover/acre at R1 stage; Foliar Blend, 32 oz/acre/application with applications made at the V3 and R1 stages; SoyAstim-27, 32 oz/acre/application at the V3 and R1 stages.

† Fertilizer treatments consisted of 0-0 (0 lb P_2O_5 and 0 lb K_2O/acre) or 60-80 (60 lb P_2O_5 and 80 lb K_2O/acre).

‡ NS = not significant ($P > 0.10$)

Table 7. Soybean leaf nutrient concentrations at the R1 stage as affected by preplant P and K fertilization rate, averaged across foliar-applied product treatments, at the Cross County (Cross-PK) and Pine Tree Research Station (PTRS-PK) sites during 2012.

	Cross-PK		PTRS-PK	
Leaf nutrient	0-0*	60-80*	0-0	60-80
	(bu/acre†)			
P	0.40 a	0.41 a	0.21 a	0.21 a
K	1.66 b	1.74 a	0.97 b	1.09 a
Ca	0.92 b	0.98 a	1.19 a	1.17 a
Mg	0.35 b	0.37 a	0.47 a	0.43 b
S	0.26 a	0.27 a	0.21 a	0.21 a
Fe	89 a	95 a	81 a	83 a
Mn	58 a	61 a	189 a	184 a
Zn	62 a	62 a	45 a	45 a
Cu	12.6 a	12.0 b	6.9 a	7.0 a
B	23.0 a	22.8 a	27.5 a	25.9 b

* Fertilizer treatments consisted of 0-0 (0 lb P_2O_5 and 0 lb K_2O/acre) or 60-80 (60 lb P_2O_5 and 80 lb K_2O/acre).

† Nutrient concentration means between P and K fertilizer rates within the same site followed by different letters indicates that values were significantly different at the 0.10 level.

Soybean and Rice Growth and Yield Responses to Phosphorus and Potassium Fertilization Rate and Time

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BACKGROUND INFORMATION AND RESEARCH PROBLEM

Phosphorus (P) and potassium (K) fertilizers are usually applied within a few days or weeks before a summer-grown crop is planted. However, after the summer-grown crop is harvested, if weather and soil conditions permit, many farmers try to prepare fields for planting the following spring. Fall field preparation usually includes managing the previous crop's residue, tillage, and application of P and K fertilizers. This practice has become more common in part because the number of acres farmed continues to increase making time management more important. We have no farmer survey results or statistics to indicate an increased frequency for fertilizer to be fall-applied to fields that will be used for row crop production the following year, but the number of questions regarding fall-fertilization has increased since 2007, when fertilizer prices increased dramatically.

As a general rule, the University of Arkansas Cooperative Extension Service has discouraged growers from fall applying P and K fertilizers due to soil reactions (i.e., fixation) that could reduce plant availability of fertilizer nutrients across time and the increased risk of nutrient loss via erosion, runoff, and/or leaching. Applying nutrients closest to the time of plant use is considered a best management practice. Research conducted with soybean [*Glycine max* (L.) Merr.] double-cropped following soft red winter wheat (*Triticum aestivum* L.) harvest suggests that nutrient application rate is more critical than the time of fertilizer application (Slaton et al., 2009). Knowledge of how nutrient application time influences crop response to fertilization will become increasingly important as poultry litter or commercial fertilizers are applied weeks or months in advance of crop planting. Our research objectives were to i) evaluate soybean and rice (*Oryza sativa* L.) grain yield, tissue P and K concentration, and aboveground nutrient uptake (rice only) responses to fertilizer applied in the fall, winter, and or early spring (before planting) on soils having below optimum soil-test P and K levels, and ii) soil-test P and K responses to sample time and nutrient application time and rate.

PROCEDURES

Research was established on a soil mapped as a Calloway silt loam at the Pine Tree Research Station (PTRS). The site had been cropped to soybean the previous year without P and K fertilization. Composite soil samples were collected (0- to 4-in.) on 26 October 2011, 29 February 2012, and 28 March for rice or 16 April 2012 for soybean from one plot in each block designated to receive no P or K fertilizer. Soil samples were analyzed for soil pH (1:2 soil/water volume mixture), Mehlich-3 extractable nutrients, and organic matter by weight loss on ignition. Selected soil chemical property means from the April 2012 sample time are listed in Table 1. Selected soil property means for the three sample times are compared in Table 2. In mid-April 2012, in the soybean trial areas, composite soil samples were collected from each plot to examine how P and K fertilizer applied in October 2011 and February 2012 affected soil-test P and K (Table 3).

Phosphorus- (as triple superphosphate) and K-fertilizer (as muriate of potash) treatments were hand broadcast to the soil surface at rates of 0, 45, and 90 lb K_2O or P_2O_5/acre on 26 October 2011, 29 February 2012, and 28 March (for rice) or 17 April 2012 (for soybean). The K research area received 50 lb P_2O_5/acre as triple superphosphate and the P area received 60 lb K_2O/acre as muriate of potash in April. Wells rice was drill-seeded (7.5-in. row spacing) into an untilled seedbed on 28 March 2012. Rice was fertilized with 130 lb urea-N/acre on 15 May 2012 and a 4-in. deep flood was established within 2 days. Whole aboveground plant samples were collected from a 3-ft section of an inside row at the midtillering stage in the P trial (5 June) and at the late boot stage (11 July) of the K trial. Samples were dried to a constant moisture, weighed for dry matter determination, ground to pass a 1-mm sieve, a subsample was digested in concentrated HNO_3 and 30% H_2O_2, and the digests analyzed for nutrient concentration. Total P or K uptake was calculated as the product of dry matter and nutrient concentration. Rice was harvested with a plot combine, grain weight and moisture content were recorded, and grain yields were adjusted to a uniform moisture content of 12% for statistical analysis.

Soybean (Armor 48-R40) was drill-seeded (15-in. wide rows) into an undisturbed seedbed on 26 April. Soybeans were flood irrigated as needed during the growing season. Fully expanded trifoliate leaves (15/plot) from one of the top three nodes of soybean plants were collected in each plot at the R3 (5 July) growth stage. Plant samples were processed as described for rice to determine leaf nutrient concentrations. The middle rows of each soybean plot were harvested with a plot combine, grain weight and moisture content were recorded, and grain yields were adjusted to a uniform moisture content of 13% for statistical analysis.

Each experiment was a randomized complete block design with a 2 (fertilizer rate) × 3 (application month) factorial treatment arrangement compared to a no fertilizer (P or K) control. Each treatment was replicated six times and each replicate contained two no P or K fertilizer control plots. Soil-test P and K values from the April (soybean) 2012 sample time were subjected to analysis of variance (ANOVA) to evaluate the effect of fertilizer applied in October and February on soil-test P and K using a 2 (fertilizer rate) × 2 (application month) factorial treatment arrangement plus the no fertilizer control (n =12). A second ANOVA was performed on selected soil chemical property data from plots designated to receive no P or K fertilizer and sampled in October, February, and March (rice) or April (soybean) to determine the effect of sample month. Data were pooled across the four test areas resulting in 24 replicates per treatment. Crop nutrient concentration and grain yield data were analyzed by trial using a 2 (fertilizer rate) × 3 (application month) factorial treatment arrangement compared to a no fertilizer (P or K) control with each treatment replicated six times. All statistical analyses were performed with the GLM procedure in SAS v9.2 (SAS Institute Inc., Cary, N.C.) with significant differences interpreted when $P < 0.05$ for soil data and $P < 0.10$ for yield and plant nutrient concentration data.

RESULTS AND DISCUSSION

Soil-Test Results as Affected by Month of Sample Collection

Mehlich-3 extractable P was not affected by soil sample collection time, but month of soil sample collection resulted in significant differences in soil pH, soil organic matter, and Mehlich-3 extractable K and Zn (Table 2). The mean soil pH varied by 0.3 units between October 2011 and April 2012 being highest in February and lowest immediately before planting in late March or mid-April. Soil organic matter ranged from 2.39% to 2.55% being lowest in October 2011 and equal for the February and March/April sample times. For P, soil samples collected on all dates had 'Very Low' (<16 ppm) soil-test P levels differing by less than 1 ppm. Soil-test K was greatest in October 2011 and declined to a constant value for the February and March/April 2012 sample times. The change in soil-test K was also of practical significance since the soil-test level and fertilizer rate recommendations would also have changed. The soil-test K level declined from Medium (91-131 ppm) for the October 2011 samples to Low (61-90 ppm) for the February and March/April sample times, which was near the Low-Medium boundary. Similar decreases in soil-test K across time have been reported in Arkansas (Slaton et al., 2010b). Soil-test Zn ranged from 1.17 to 1.37 ppm Zn and was lowest in October 2011 and greatest for samples collected in February and March/April 2012.

Soil-test K

Soil-test K in April 2012 was not significantly affected by the main effect of fertilizer application month ($P < 0.3273$), averaged across K rates, or the interaction between fertilizer application month and K-fertilizer rate ($P = 0.1558$). Only K-fertilizer rate ($P = 0.0014$), averaged across fertilizer application time, significantly affected soil-test K in April 2012. Soil-test K increased numerically with each increase in K rate, but the only significant difference was that soil fertilized with 90 lb K_2O/acre (120 ppm K, LSD0.010 = 10 ppm) had a greater soil-test K than soil fertilized with 0 (94 ppm K) or 45 lb K_2O/acre (103 ppm K). Using a soil bulk density value of 1.20 g/cm^3 as outlined by Slaton et al. (2010b), the theoretical maximum that soil-test K would increase from the applied K fertilizer rates would be 35 and 70 ppm. However, soil-test K increased by only 9 ppm (26% recovery) or 26 ppm (37% recovery) for the 45 and 90 lb K_2O/acre rates, respectively.

Soil-test P

Soil-test P was affected by the interaction between fertilizer application month and P rate (Table 3). Soil-test P was increased by P fertilization with soil-test P being greatest and equal among 90 lb P_2O_5/acre applied in October 2011 and February 2012, and 45 lb P_2O_5/acre applied in February 2012. Application of 45 lb P_2O_5/acre applied in October 2011 produced an intermediate soil-test P that was greater only than soil that received no P. These results suggest that as time between P fertilization increases the soil fixes the P into forms that become less extractable and perhaps less available to the plant and that soil-test P tends to increase more as P rate increases. Using the same bulk density assumption outlined for K, the maximum possible increase in soil-test P would be 18.5 and 37 ppm P from application of 45 and 90 lb P_2O_5/acre, respectively. The Mehlich-3 soil extractant recovered 18% to 21% of P fertilizer applied as 45 lb P_2O_5/acre applied in October 2011 and 90 lb P_2O_5/acre in October 2011 or February 2012. Recovery was 47% of the 45 lb P_2O_5/acre application made in February 2012.

Soybean Trifoliate Leaf Concentrations and Yield

Soybean leaf K concentration was affected by K fertilizer rate, averaged across K application month ($P = 0.0020$), but not by application month ($P = 0.1734$) or the application month by rate interaction ($P = 0.7799$). Soybean fertilized with 90 lb K_2O/acre (1.89% K; LSD0.10 = 0.08% K) had greater trifoliate leaf K concentrations than soybean fertilized with 0 (1.75% K) or 45 (1.75% K) lb K_2O /acre. Seed yield was influenced only by the interaction between K fertilizer application month and rate ($P = 0.0944$, Table 4). Although yields varied somewhat among the treatments, the general trend was for soybean that received 90 lb K_2O/acre to produce numerically and sometimes significantly greater yields than soybean receiving 0 or 45 lb K_2O/acre.

Trifoliate-leaf P concentrations were not affected by P fertilizer rate ($P = 0.6261$), application month ($P = 0.2556$), or their interaction ($P = 0.2377$) with the average leaf P concentration of 0.332% P. Although not significant, leaf P concentration increased numerically as P rate increased. Likewise and despite the Very Low soil-test P level, soybean grain yield was not affected by P fertilizer rate ($P = 0.4968$), application month ($P = 0.9072$) or their interaction ($P = 0.7243$) with the average grain yield of 71 bu/acre (individual treatment yield range 69 to 73 bu/acre).

Rice Growth, Nutrient Uptake, and Grain Yield

Rice dry matter, whole plant K concentration, and aboveground K content at the late boot stage and grain yield were not significantly affected by K fertilization rate, K application time, or their interaction (Table 5). These results suggest that this site was not responsive to K fertilization, which would not be overly surprising since the soil-test K level was Medium in October 2011 and near the Low–Medium boundary in February and March 2012.

Rice dry matter accumulation at midtillering and grain yield also failed to benefit from P fertilization despite having a Very Low soil-test P (Table 6). The near neutral pH (Table 1) may have allowed sufficient available P for optimal rice growth since P deficiency tends to be more common on soils with a pH > 7.5 and Very Low soil-test P levels. The interaction between P rate and fertilizer application time significantly affected tissue P concentration and content (i.e., uptake) at the midtillering stage (Table 7). Tissue P concentration tended to be greatest when rice was fertilized with 90 lb P_2O_5/acre at all applications except the March application time. Application of 45 lb P_2O_5/acre at all application times and 90 lb P_2O_5/acre applied at planting (March) had little or no influence on rice P concentration. There was no identifiable and consistent trend in the total P uptake results. The results from the 2012 P and K trials are comparable with those from previous trials with rice (Slaton et al., 2010a; 2012).

PRACTICAL APPLICATIONS

Rice and soybean yields were not affected by the different P fertilization rates or the month of fertilizer application. Soybean yields were affected by K fertilization, but the month of fertilizer application showed no consistent trend suggesting that nutrient application rate is the more important factor influencing crop response to fertilization. Plant tissue P and K concentrations also suggest that K fertilizer applied at different times was taken up with equal efficiency by rice and soybean. In the absence of growth, yield, or nutrient uptake differences to fertilization, we cannot make conclusive statements regarding whether fertilizer application time is of significant or practical concern on nutrient-deficient soils.

We did learn that less than one-half of the fertilizer applied 2 to 6 months before soil sample collection was recovered by the Mehlich-3 extractant, which is consistent with our previous results. To best assess the availability of soil nutrients with soil tests, growers are advised to collect soil samples before manure or fertilizer is applied to fields. The soil-test values for P and K appear to be more consistent when soil samples are collected in February through April rather than in October or November.

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Table 1. Selected soil chemical property means (0- to 4-in. depth) at the Pine Tree Research Station used to evaluate soybean and rice response to P and K fertilization rate and time as determined from soil samples collected in late March (rice) or mid-April (soybean) 2012.

Crop-	Soil	Soil	Mehlich-3 extractable soil nutrient concentrations[b]								
nutrient	OM	pH[a,b]	P[c]	K[d]	Ca	Mg	S	Fe	Mn	Zn	Cu
	(%)		(ppm)								
Soybean-P	2.6	6.9	14	88	1385	239	17	223	366	1.3	1.2
Soybean-K	2.5	6.8	13	95	1361	236	15	223	366	1.1	1.1
Rice-P	2.5	6.8	17	89	1499	240	13	221	402	1.6	1.4
Rice-K	2.6	6.9	14	89	1491	246	13	229	368	1.5	1.4

[a] Soil pH measured in a 1:2 soil:water volume mixture.
[b] Mean of 6 composite samples (0- to 4-in. depth) from plots designated to receive no P or K fertilizer.
[c] For P trials, the standard deviation of mean soil-test P was 2.7 ppm in the soybean-P trial and 3.1 ppm in the rice-P trial.
[d] For K trials, the standard deviation of mean soil-test K was 14 ppm in the soybean-K trial and 10 ppm in the rice-K trial.

Table 2. The effect of sample month on the soil pH and Mehlich-3 extractable P, K, and Zn concentrations of soil receiving no P or K fertilizer at the Pine Tree Research Station in 2011 and 2012. Values represent the mean of 24 soil samples collected at each sample time from plots that received no P or K from four adjacent trial areas.

Sample	Soil organic		Mehlich-3 Soil Test		
month	matter	Soil pH[a]	P	K	Zn
	(%)		(ppm)		
October	2.39	6.9	15	116	1.2
February	2.48	7.2	14	89	1.4
April	2.55	7.1	14	90	1.4
LSD0.05	0.09	0.1	NS[b]	3	<0.1
P-value	0.0017	<0.0001	0.2200	<0.0001	<0.0001
C.V., %	5.9	1.8	8.5	4.4	5.3

[a] Soil pH measured in a 1:2 soil:water volume mixture
[b] NS = not significant ($P < 0.05$).

Table 3. The effect of fertilizer application month and P-fertilizer rate on Mehlich-3-extractable soil P as determined in April 2012 at the Pine Tree Research Station.

Fertilizer application time	45 lb P_2O_5/acre		90 lb P_2O_5/acre
		(ppm P)	
No P applied		14	
October 2011	17		20
February 2012	22		21
LSD0.10		2.4	
P-value		0.0071	
C.V., %		11.1	

Table 4. Soybean seed yield as affected by the interaction between K-fertilizer application month and K-fertilizer rate at the Pine Tree Research Station in 2012.

Fertilizer application time	45 lb K_2O/acre		90 lb K_2O/acre
		(bu/acre)	
No K fertilizer		69	
October 2011	71		70
February 2012	67		71
April 2012	69		74
LSD0.10		3	
C.V., %		4.8	

Table 5. Rice growth, K concentration and content, and grain yield as affected by K application rate, averaged across K application month, for a trial conducted at the Pine Tree Research Station in 2012.

K rate	Dry matter	Whole plant K concentration	Aboveground K uptake	Grain yield
(lb K_2O/acre)	(lb/acre)	(% K)	(lb K/acre)	(bu/acre)
0	11425	1.70	193	226
45	11039	1.71	186	223
90	11332	1.83	203	228
LSD0.10	NS[a]	NS	NS	NS
C.V., %	14.2	11.0	20.2	4.5
ANOVA[b]				
K Rate (KR)	0.5248	0.0747	0.2050	0.1668
Month (M)	0.9772	0.4937	0.9505	0.1514
KR × M	0.8912	0.4003	0.6619	0.1589

[a] NS = not significant ($P > 0.10$).
[b] ANOVA = analysis of variance *P*-values.

Table 6. Rice dry matter accumulation, P concentration and content (uptake) at the midtillering stage, and grain yield as affected by P application rate, averaged across P application month, for a trial conducted at the Pine Tree Research Station in 2012.

P rate	Dry matter	Whole plant P concentration	Aboveground P uptake	Grain yield
(lb P_2O_5/acre)	(lb/acre)	(% P)	(lb P/acre)	(bu/acre)
0	1528	0.23	3.5	206
45	1495	0.22	3.3	206
90	1565	0.23	3.7	206
LSD0.10	NS[a]	NS	NS	NS
C.V., %	22.9	10.0	27.3	5.8
ANOVA[b]				
K Rate (KR)	0.6394	0.1131	0.3420	0.9695
Month (M)	0.2029	0.0231	0.1217	0.9747
KR × M	0.1315	0.0237	0.0857	0.3056

[a] NS = not significant ($P > 0.10$).
[b] ANOVA = analysis of variance *P*-values.

Table 7. Rice P concentration and aboveground P uptake at the midtillering stage as affected by the interaction between P application rate and P application month, for a trial conducted at the Pine Tree Research Station in 2012.

P application time	P concentration		Aboveground P uptake	
	45 lb P_2O_5/acre	90 lb P_2O_5/acre	45 lb P_2O_5/acre	90 lb P_2O_5/acre
	---------- (% P) ----------		---------- (lb P/acre) ----------	
None	0.225		3.5	
October 2011	0.228	0.253	3.7	3.6
February 2012	0.212	0.242	3.1	4.5
March 2012	0.223	0.205	3.1	2.9
LSD0.10	0.022		0.9	

Midland 99 Bermudagrass Forage Yield Response to Two Years of Phosphorus and Potassium Fertilization

N.A. Slaton, C.G. Massey, R.E. DeLong, and B. Haller

BACKGROUND INFORMATION AND RESEARCH PROBLEM

Warm- and cool-season forages produced for hay were grown on 1.48 million acres in Arkansas during 2010 making hay forage one of the most widely cultivated crops in Arkansas (USDA-NASS, 2011). The median soil-test phosphorus (P) and potassium (K) for warm-season forages has declined by 6.0 and 8.9 ppm/year, respectively, since 2006 (Fig. 1) suggesting that farmers are not fertilizing these forages sufficiently with K. The median soil-test K is considered low and yield limiting while median soil-test P is still above optimum. The decline in median soil-test P and K is likely related to the nutrient management regulations that limit poultry litter application. These trends call for research and education programs to ensure that sufficient soil fertility is maintained to prevent bermudagrass stand decline, soil erosion, and reduced water quality. We have previously reported on a project examining selected soil chemical property and common bermudagrass responses to annual P and K fertilizer management during a 5-year period (Slaton et al., 2011). This report summarizes the second year of similar P and K research that was initiated in 2011 on a site with sub-optimal soil P and K availability. Our research objective was to evaluate soil-test P and K and Midland 99 bermudagrass yield and nutrient uptake as affected by annual P and K fertilization. The overall goal of this forage research effort is to develop and/or verify current soil-test based fertilizer recommendations for bermudagrass forage grown for hay.

PROCEDURES

Fertilization research was initiated in April 2011 on a Barling silt loam with an established stand of Midland 99 bermudagrass on a commercial farm located in El Paso, Ark. (Slaton et al., 2012). In March 2012, composite soil samples (five 1-in.-wide cores/composite) were collected from each plot to a depth of 4 in. to monitor changes in soil-test P and K following the first year of fertilization. Soils were dried at 130 °F, crushed to pass a 2-mm diameter sieve, analyzed for water pH (1:2 soil/water volume ratio), and extracted for plant-available nutrients using the Mehlich-3 method (Table 1).

In the K rate trial, muriate of potash was applied in two or three applications for cumulative season-total rates equaling 0, 90 (45 × 2), 180 (60 × 3), 270 (90 × 3), 360 (120 × 3), and 450 (150 × 3) lb K_2O/acre. Potassium fertilizer treatments were applied on 23 April (green-up), 27 June following the second harvest, and 31 July following the third harvest. Phosphorus [150 lb 12-40-0-10S-1Zn/acre, sold as MicroEssentials (MESZ)] and N fertilizers (260 lb urea/acre) were broadcast-applied to the K rate trial at greenup. After each subsequent harvest the area received 80 to 100 lb urea-N plus 100 lb MESZ /acre.

In the P rate trial, triple superphosphate was applied in one to three split applications for cumulative rates equivalent to 0, 30 (× 1), 60 (30 × 2), 90 (30 × 3), 120 (40 × 3), and 150 (50 × 3) lb P_2O_5/acre. Fertilizer application dates were the same as given for the K rate trial. The P research area received 150 lb muriate of potash/acre and 260 lb urea/acre at greenup. Following each harvest, the area received 150 lb muriate of potash and 80 to 100 lb urea-N/acre.

In each trial, forage was harvested by cutting an 18-ft long × 3.8-ft wide swath with a self-propelled, cycle-bar mower at a height of 2.0 to 2.5 in. Forage was harvested on 29 May, 27 June, 31 July, and 20 September. Hay harvests were scheduled for every 30 days, but were adjusted according to growth and weather conditions. The biomass from each plot was weighed and adjusted to total dry weight expressed as lb dry forage/acre. A subsample of forage from each plot was dried to determine moisture content, ground to pass a 1-mm sieve, and digested in concentrated HNO_3 and 30% H_2O_2 to determine forage P and K concentrations and total nutrient uptake and removal.

Each experiment was a randomized complete block design with each fertilizer rate replicated five times. Analysis of variance procedures were performed with PROC MIXED in SAS (SAS Institute, Inc., Cary, N.C.). Forage yield, nutrient concentration, and nutrient uptake data were analyzed by harvest time and for the season total production (sum of each harvest). Initial soil-test data were analyzed as a randomized complete block design. When appropriate, mean separations were performed using Fisher's Protected Least Significant Difference method at a significance level of 0.10.

RESULTS AND DISCUSSION

The summer of 2012 was hot and dry and the lack of moisture significantly and adversely affected forage growth. The amount of precipitation received at the Little Rock Air

Force Base Weather Station (~25 miles from plots) during the months of April (0.84 in.), May (0.48 in.), June (0.04 in.), and July (1.4 in.) was less than 50% of the historical normal precipitation while monthly average temperatures were 2.9 °F to 5.2 °F above normal from April through July. Significant rainfall to sustain rapid forage growth did not occur until late August and early September.

The initial soil chemical properties at this site were uniform among plots designated to receive each treatment and characterized as near optimal soil pH, 'Very Low' soil-test P (< 16 ppm) and 'Low' soil-test K (61 to 90 ppm, Table 1). One year of fertilization and cropping changed the subsequent soil-test P and K values (Table 2). Based on the first year of data, soil-test K changed by 1 ppm for every 7.9 lb K_2O/acre [Mehlich-3 ppm K = 38.8 + 0.126x, where x = annual K_2O rate; $r^2 = 0.80$] and soil-test P changed by 1 ppm for every 20.0 lb P_2O_5 applied/acre [Mehlich-3 P ppm = 15.8 + 0.050x, where x = annual P_2O_5 rate; $r^2 = 0.30$]. The stand of Midland 99 bermudagrass appeared to be more uniform in 2012, but the amount of dallisgrass also increased.

Single-degree-of-freedom contrasts showed that forage receiving K produced greater yields than forage that received no K for each of the first three harvests and the season total yield (Table 3). Forage dry matter yield for the first and second harvests and the season total yield were affected by K fertilization rate in 2012. Season total forage yield increased numerically as K rate increased and was maximized by application of 180 to 450 lb K_2O/acre/year. For the first harvest, forage receiving K produced equal yields that were significantly greater than yields of the no K control. For the second harvest, forage receiving 270 to 450 lb K_2O/acre/year produced greater yields than forage that received 0 to 180 lb K_2O/acre/year. Yield results for the second harvest suggest that only the moderate and high K rates provided enough residual K availability (from previous applications) to produce maximal yield since no K was applied to any plot following the first harvest.

Based on single-degree-of-freedom contrasts, P fertilization increased forage yields for the first, second, and fourth harvests plus the sum of all four harvests (Table 4). Multiple mean comparisons indicated no consistent ranking among P rates with the unfertilized control producing similar cumulative yields as forage that received 120 and 30 lb P_2O_5/acre/year, but less than all other P rates. For the first harvest, the no P control did produce the lowest overall yield which was significantly lower than all other P rates except 120 lb P_2O_5/acre/year. The no P control produced the lowest numerical yield for only two of the four harvests.

Forage K concentration generally increased numerically and often significantly as annual K rate increased for each of the four harvests (Table 5). The lowest numerical K concentrations among K rates occurred during the second harvest, which is the only forage growth period that a split application of K was not applied. Although not compared statistically in this report, the K concentration within each annual K rate tended to increase with each harvest after the second harvest. The K concentration of forage receiving no K and the 90 lb K_2O/acre/year rate were considered K-deficient (<1.5%) for each harvest.

Like K concentration, total K uptake, expressed as lb K_2O/acre, was significantly affected by annual K rate for each harvest and the season cumulative uptake. Total K uptake generally followed the same trend as described for K concentration. Linear regression (not shown) of the season cumulative total K uptake means produced a slope of 0.309 lb K_2O uptake/lb K_2O applied suggesting that 30% of the applied fertilizer K was taken up by the forage. However, a quadratic equation also fit the mean values suggesting that uptake of fertilizer K declined as annual K rate increased.

According to the standards published by Plank and Campbell (2011), forage harvested from all annual P rates during the first two harvest periods was P-deficient (< 0.20% P, Table 6). Phosphorus concentrations of forage from the third harvest were borderline deficient for all annual P rates. The lack of rain may have inhibited P movement into the soil for plant uptake. A similar trend was observed in 2011, which was also a dry year (Slaton et al., 2012). Despite the low P concentrations and the lack of significant differences among treatments, forage P concentration increased numerically with each increase in annual P rate. Total P uptake differed among annual P rates only for the first and fourth forage harvest and the season total forage P uptake, expressed as lb P_2O_5/acre. The single-degree-of-freedom contrast comparisons also indicated differences in P uptake between forage that received no P and forage receiving P fertilizer at these same harvests. On average, each ton of forage produced contained from 17 to 51 lb K_2O and 7.3 to 11.6 lb P_2O_5. The K content of each ton of harvested forage tended to increase numerically (statistical analysis not performed) as K rate increased suggesting that luxury consumption increased numerically as K rate increased but remained relatively constant across P rates (data not shown). This trend was less noticeable for the P content in harvested forage.

PRACTICAL APPLICATIONS

The second year of P and K fertilization research on Midland 99 bermudagrass conducted in 2012 showed significant changes in soil-test P and K from the first year of fertilization but forage yield increases to P and K fertilization were not consistent. The lack of consistent forage responses to P and K fertilization were presumably due to the hot, dry conditions which were unfavorable for forage growth. These trials will be continued in 2013.

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Table 1. Selected soil chemical property means (*n* = 30; 0- to 4-in. depth) for bermudagrass P and K fertilization trials conducted on a Barling silt loam in El Paso, Ark., in 2011 and 2012.

Year and nutrient	Soil organic matter	Soil pH	Mehlich-3 extractable nutrients									
			P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu
	(%)		mean (standard deviation) in ppm									
2011-K	1.8[a]	6.2	14	82 (12)	804	50	13	12	116	153	0.6	0.3
2012-K	1.9	5.5	46	--	704	46	13	11	144	169	1.5	0.4
2011-P	2.0	5.7	11 (3)	73	751	71	13	16	128	182	0.6	0.3
2012-P	1.9	5.2	--	97	637	69	16	11	142	190	10.6	0.5

[a] n = 5 for soil organic matter (analyzed from the plots receiving no P or K fertilizer).

Table 2. Mehlich-3 extractable soil P and K in 2011 before fertilization with P and K and 2012 after one year of fertilization and cropping.

	Potassium trial			Phosphorus trial	
Annual K rate	2011	2012	Annual P rate	2011	2012
(b K_2O/acre)	----(Mehlich-3 K, ppm)----		(lb P_2O_5/acre)	--- (Mehlich-3 P, ppm)----	
0	87	40	0	11	15
90	73	49	30	13	17
180	81	59	60	11	19
270	79	77	90	12	24
360	82	82	120	10	20
450	87	97	150	12	22
LSD0.05	NS[a]	11	LSD0.05	NS	5
P-value	0.3946	<0.00001	*P*-value	0.5608	0.060
C.V.,%	14.0	14.3	C.V., %	25.0	17.8

[a] NS = not significant ($P > 0.05$).

Table 3. Forage dry matter yields by harvest during 2012 as affected by K fertilization rate for a trial conducted on a Barling silt loam in El Paso, Ark.

Season total K_2O rate[a]	Season total	Harvest 1 (29 May)	Harvest 2 (27 June)	Harvest 3 (31 July)	Harvest 4 (20 Sept.)
(lb K_2O/acre)	(lb forage/acre)				
0	8532	2617	1592	1857	2514
$90^{\times 2}$	9510	3681	1714	1985	2191
$180^{\times 3}$	10283	4009	1795	2058	2507
$270^{\times 3}$	11127	4361	2154	2013	2704
$360^{\times 3}$	10775	4082	2257	2099	2384
$450^{\times 3}$	11145	3974	2308	2288	2691
LSD(0.10)	1067	65	352	NS[b]	NS
P-value	0.0022	0.0355	00064	0.1337	0.2766
C.V., %	9.6	20.9	16.4	11.2	14.8
SDF[c]	0.0001	0.0012	0.0033	0.0364	0.7592

[a] The superscripted value indicates the number of split applications needed to apply the season-total K rate. Potassium fertilizer treatments applied at greenup and after the June and July harvests.

[b] NS = not sigificant ($P > 0.10$).

[c] SDF = single-degree-of-freedom contrast comparing the no K control against the mean yield of bermudagrass fertilized with 180 to 450 lb K_2O/acre.

Table 4. Forage dry matter yields by harvest during 2012 as affected by P fertilization rate for a trial conducted on a Barling silt loam in El Paso, Ark.

Season total P_2O_5 rate[a]	Season total	Harvest 1 (29 May)	Harvest 2 (27 June)	Harvest 3 (31 July)	Harvest 4 (20 Sept.)
(lb P_2O_5/acre)	(lb forage/acre)				
0	9504	3549	1732	1894	2351
$30^{\times 1}$	10074	4409	1629	1613	2427
$60^{\times 2}$	10685	4628	1670	1805	2614
$90^{\times 3}$	11479	4955	1829	1878	2848
$120^{\times 3}$	9436	3789	1497	1571	2562
$150^{\times 3}$	10540	4231	1708	1860	2737
LSD(0.10)	962	625	NS[b]	NS	NS
P-value	0.0126	0.0093	0.7220	0.4860	0.3768
C.V., %	8.6	13.4	19.6	18.6	15.1
SDF[c]	0.0299	0.0075	0.7378	0.4933	0.0984

[a] The superscripted value indicates the number of split applications needed to apply the season-total P rate. Phosphorus fertilizer treatments applied at greenup and after the June and July harvests.

[b] NS = not sigificant ($P > 0.10$).

[c] SDF = single-degree-of-freedom contrast comparing the no K control against the mean yield of bermudagrass fertilized with 60 to 150 lb P_2O_5/acre.

Table 5. Forage K concentration and aboveground K uptake by harvest during 2012 as affected by K fertilization rate for a trial conducted on a Barling silt loam in El Paso, Ark.

	Forage K concentration				Aboveground potassium uptake				
Season total K_2O rate[a]	Harvest 1 (May 29)	Harvest 2 (June 27)	Harvest 3 (July 31)	Harvest 4 (Sept 20)	Season total	Harvest 1 (May 29)	Harvest 2 (June 27)	Harvest 3 (July 31)	Harvest 4 (Sept 20)
(lb K_2O/acre)	(% K)				(lb K_2O/acre)				
0	0.72	0.72	1.00	1.03	90	22	14	23	31
$90^{\times 2}$	1.10	0.86	1.10	1.38	127	48	18	26	36
$180^{\times 3}$	1.30	1.01	1.39	1.68	168	61	22	35	50
$270^{\times 3}$	1.37	1.24	1.55	1.89	203	72	32	38	61
$360^{\times 3}$	1.50	1.25	1.67	2.09	210	74	34	42	60
$450^{\times 3}$	1.44	1.39	1.91	2.12	228	68	40	52	68
LSD(0.10)	0.156	0.144	0.195	0.12	27	19	8	7	7
P-value	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0012	<0.0001	<0.0001	<0.0001
C.V., %	11.6	12.3	12.5	6.6	14.2	30.1	26.9	18.8	12.4
SDF[b]	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

[a] The superscripted value indicates the number of split applications needed to apply the season-total K rate. Potassium fertilizer treatments applied at greenup and after the June and July harvests.

[b] SDF = single-degree-of-freedom contrast comparing the no K control against the mean yield of bermudagrass fertilized with 180 to 450 lb K_2O/acre.

Table 6. Forage P concentration and aboveground P uptake by harvest during 2012 as affected by P fertilization rate for a trial conducted on a Barling silt loam in El Paso, Ark.

	Forage P concentration				Aboveground phosphorus uptake				
Season total P_2O_5 rate[a]	Harvest 1 (May 29)	Harvest 2 (June 27)	Harvest 3 (July 31)	Harvest 4 (Sept 20)	Season total	Harvest 1 (May 29)	Harvest 2 (June 27)	Harvest 3 (July 31)	Harvest 4 (Sept 20)
(lb P_2O_5/acre)	(% P)				(lb P_2O_5/acre)				
0	0.162	0.178	0.197	0.228	40.8	13.1	7.1	8.4	12.3
$30^{\times 1}$	0.166	0.183	0.206	0.240	44.6	16.9	6.8	7.7	13.3
$60^{\times 2}$	0.166	0.181	0.202	0.235	46.6	17.6	6.8	8.2	14.6
$90^{\times 3}$	0.162	0.176	0.207	0.242	50.0	18.1	7.3	8.9	15.7
$120^{\times 3}$	0.166	0.176	0.203	0.257	42.6	14.5	6.0	7.2	14.9
$150^{\times 3}$	0.171	0.185	0.204	0.253	48.2	16.5	7.2	8.8	15.8
LSD(0.10)	NS[b]	NS	NS	NS	4.4	2.7	Ns	NS	2.2
P-value	0.8219	0.9160	0.9581	0.1280	0.0164	0.0315	0.7185	0.7008	0.0738
C.V., %	7.3	8.6	8.6	7.0	8.9	15.2	19.7	23.3	14.0
SDF[b]	0.4821	0.8485	0.4541	0.0438	0.0073	0.0081	0.7158	0.8645	0.0113

[a] The superscripted value indicates the number of split applications needed to apply the season-total P rate. Phosphorus fertilizer treatments applied at greenup and after the June and July harvests.

[b] SDF = single-degree-of-freedom contrast comparing the no P control against the mean yield of bermudagrass fertilized with 180 to 450 lb P_2O_5/acre.

Soybean Yield Response to a Maximum Yield Environment

R.J. Van Roekel and L.C. Purcell

BACKGROUND INFORMATION AND RESEARCH PROBLEM

The highest Arkansas statewide average soybean [*Glycine max* (L.) Merr.] yield was 39 bu/acre, which occurred in 2004 (USDA-NASS, 2010). The United States average soybean yields have increased from the earliest record of 11 bu/acre in 1924 to a high of 44 bu/acre in 2009 (USDA-NASS, 2011). While this increase in soybean yield over time is substantial, both researchers and growers have documented yields much higher than both the reported national and state averages. For example, in New Jersey, Dr. Roy Flannery recorded his highest soybean yield of 118 bu/acre in 1983 and a 5-yr average irrigated yield of 103 bu/acre (Flannery, 1989).

The highest soybean yield recorded to date was reported by the Missouri Soybean Association for Mr. Kip Cullers of southwest Missouri who won their 2010 yield contest with a yield of 161 bu/acre (Cubbage, 2010). These abnormally high yields have created some controversy and due skepticism by certain experts in the field. Research was undertaken at the University of Arkansas, Fayetteville, to attempt to duplicate Mr. Cullers' yields and provide insights into the key management practices for achieving soybean yields of this magnitude.

PROCEDURES

A small-plot trial was established in 2012 at the Arkansas Agricultural Research and Extension Center in Fayetteville, Ark., on a Leaf silt loam (fine, mixed, active, thermic, Typic Albaquults). Plots consisted of four rows, 18 in. apart, and 30 ft long. Treatments (cultivars) were arranged in a randomized complete block design with four replications. The previous crop was soft red winter wheat (*Triticum aestivum* L.). A composite soil sample was collected to a depth of 4 in. on 13 September 2011. Soil samples were dried, ground, and analyzed for pH with a 1:2 soil/water weight ratio, extracted with Mehlich-3 solution, and concentrations measured by inductively coupled plasma spectroscopy (ICPS). Soil chemical properties are listed in Table 1. Additional soil samples for pH were taken on 17 October 2011 in 50 ft increments along the length of the field for subsequent lime application. Based upon soil tests and Mr. Cullers' recommendations, lime was applied at a variable rate. Additionally, 250 lb/acre muriate of potash, 250 lb/acre $K_2Mg(SO_4)_2$, 80 lb/acre $ZnSO_4$, 100 lb/acre NH_4SO_4, and 6.2 ton/acre of poultry litter were applied and incorporated on 17 November 2011. The field was then deep ripped with a V-Till (Bigham Brothers, Lubbock, Texas) to a depth of ≥14 in. On 16 March 2012, an additional 3.7 ton/acre of litter was applied and incorporated. Four subsamples from each litter application were analyzed for total nutrient content. Litter nutrient analyses are listed in Table 2.

Twelve indeterminate varieties from Monsanto, Syngenta, and Pioneer, ranging from maturity group 4.2 to 5.5 (Table 3), were planted on 11 April 2012. All seeds were treated with 2 oz/cwt BioForge ST, 3 oz/cwt Optimize 400, 14 oz/act Accolade-(P), 8 oz/cwt Nutriplant SD, and a fungicide and insecticide, which varied by company. Final stands averaged 140,000 plants/acre. Weeds were controlled with a preplant incorporated herbicide, a post-emergence herbicide, and hand weeding as needed. Insect infestation levels were closely monitored and strictly controlled. Three preventative fungicides of rotating chemistry were applied in two-week intervals beginning at growth stage R3.

An overhead sprinkler irrigation system was installed, and irrigation was applied at a 1 in. deficit according to an irrigation scheduler (Purcell et al., 2007). The irrigation system allowed irrigation with NH_4SO_4, 32% UAN, and KNO_3, beginning at flowering. Irrigation was applied 35 times for a total of 26 in. in 2012. Supplemental fertigation totaled 264 lb N/acre, 24 lb K/acre, and 34 lb S/acre.

Various physiological measurements were taken throughout the year (data not shown). Trifoliolate leaf samples were taken from each plot, at two week intervals, starting with the beginning R5 growth stage. Leaves were dried, ground, digested, and analyzed for nutrient concentrations with ICPS. The center 20 ft of the center two rows were harvested for yield and corrected to 13% moisture. Yield data were analyzed with SAS (SAS Institute Inc., Cary N.C.) using PROC GLM. Mean separation was performed using Fisher's Protected LSD at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Growing conditions were abnormally hot and dry from June through August in 2012. Several daily high temperatures ≥95 °F coincided with the podset (R4) and seed filling (R5) stages of development (Fig. 1), and these high temperatures likely suppressed yields. Averaged across replications, varietal grain yield ranged from 115 to 86 bu/acre (Table 3).

The concentrations of selected nutrients present in the leaves near the beginning of seed fill are presented in Table 3. These results indicate that all nutrients were at sufficient-to-high levels at the beginning of seed fill. In high yield soybean, N can be a nutrient limitation for yield due to the high protein content of the seed (Salvagiotti et al., 2008). At physiological maturity (R7), variety AG5503 retained a leaf area index near 3.6 with leaf trifoliolates averaging 2.69% N (data not shown). This indicated that sufficient N was present to prevent complete "self-destruction" via translocation of vegetative N to the developing seeds (Sinclair and deWit, 1975). Thus, it was assumed that N was not limiting soybean yield in this study.

It has been theorized that initial podset is limited by the amount of photosynthate available (Egli, 1994). Early planting of these indeterminate varieties allowed flowering and initial podset (R1 to R3) to occur near the summer solstice when solar radiation should be at the highest levels. These conditions along with a closed canopy intercepting all of the light should maximize photosynthate production and podset. Furthermore, the irrigation, fertility, and pest control practices ensured that no other major limitations were placed upon the soybean crop.

PRACTICAL APPLICATIONS

Results from this research indicate that the maximum yield of soybean grown near Fayetteville, Ark., in 2012 was ≥115 bu/acre, which was nearly three times larger than the 2012 Arkansas average yield. While some of the practices utilized to achieve these yields are likely not economical, many practices can be directly applied to any soybean production field. Early planting and selecting the correct relative maturity to allow flowering and podset to occur around the summer solstice is one practice that does not have any direct cost to the grower. Besides relative maturity, variety selection in general influenced yields by 29 bu/acre. Lastly, careful attention to fertility, irrigation, and pest management are additional key factors in the "whole package" of management needed to increase soybean yield.

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Table 1. Selected soil chemical properties prior to fall fertilization for maximum yield trial in Fayetteville, Ark., in 2012.

	Soil	Mehlich-3 extractable nutrients										
Field	pH	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu	B
		(ppm)										
E3	5.7	41	60	1152	55	10	20	158	40	0.9	0.7	0.4

Table 2. Selected chemical properties of poultry litter applied for the maximum soybean yield trial in Fayetteville, Ark., in 2012.

Application	Total C	N	P_2O_5	K_2O	Ca	Mg	S	Fe	Mn	Zn	Cu
		(lb/ton on as-is basis)									
Fall 2011	610	57	47	33	53	5.3	6.6	1.3	0.5	0.4	0.2
Spring 2012	509	46	34	26	33	4.2	5.0	0.7	0.4	0.4	0.2

Table 3. Soybean grain yield and trifoliolate leaf nutrient concentrations from 3 July 2012, near beginning R5 growth stage, across four replications from Fayetteville, Ark., in 2012.

	Grain	Leaf nutrient concentration										
Variety	yield	N	P	K	Ca	Mg	S	Na	Fe	Mn	Zn	Cu	B
	(bu/acre)	(%)						(ppm)					
P94Y23	114.6 a*	5.69	0.313	1.74	1.81	0.325	0.340	21.7	93.3	96.7	115.1	12.1	43.4
P94Y80	106.4 abc	5.62	0.315	1.64	1.42	0.330	0.330	22.6	90.1	69.1	90.1	12.4	41.8
P94Y81	105.1 abc	5.82	0.315	1.70	1.56	0.358	0.348	21.0	93.1	60.6	95.4	11.3	45.4
P94Y82	95.5 cd	5.61	0.348	1.72	1.42	0.333	0.348	22.2	91.9	72.4	98.9	13.5	42.4
AG4303	98.6 bc	5.55	0.315	1.55	1.59	0.375	0.340	22.1	93.8	87.6	121.1	11.3	47.5
AG4531	96.4 bc	5.75	0.340	1.80	1.41	0.380	0.355	24.2	111.9	81.5	116.4	12.9	50.7
AG4907	104.0 abc	5.84	0.320	1.62	1.31	0.340	0.348	26.9	88.7	59.2	79.2	11.7	41.3
AG5332	106.8 ab	5.62	0.308	1.63	1.54	0.315	0.325	34.1	93.8	80.6	103.4	12.0	41.6
AG5503	97.1 bc	5.50	0.318	1.88	1.24	0.325	0.330	30.0	88.5	65.6	81.6	12.7	48.1
S44-K7	95.3 cd	5.65	0.328	1.76	1.48	0.305	0.340	25.6	94.8	82.4	116.6	13.4	50.5
S46-U6	100.3 bc	5.95	0.338	1.70	1.46	0.350	0.338	28.7	88.7	59.5	78.3	13.2	43.3
S49-A5	85.9 d	5.59	0.325	1.92	1.44	0.310	0.328	38.8	97.8	85.0	102.2	11.7	45.6

* Within a column, treatment means followed by the same letter are not significantly different (α = 0.05).

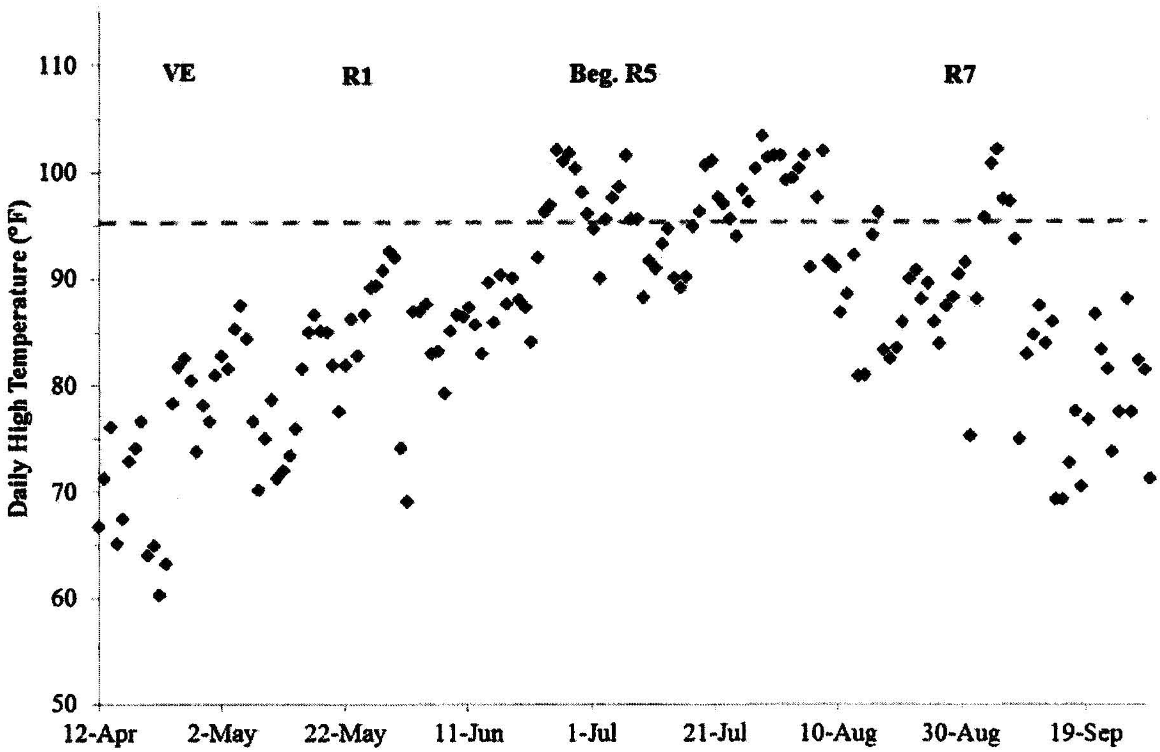

Fig. 1. Daily high temperatures and coinciding growth stages for earliest and latest variety in a maximum yield trial in Fayetteville, Ark., in 2012.

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